Appendix I.
Approach Spacing for Instrument Approaches (ASIA)

RTCA SC-186

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I.1 Operational Description for Approach Spacing for Instrument Approaches (ASIA)

I.1.1 Introduction

Managing the spacing between sequential aircraft on arrival paths in the terminal area can be challenging for both flight crew and ATC. Consequences exist for operating on either side of "optimum" spacing: If the trail aircraft is too close, a go-around may be necessary. On the other hand, if the trail aircraft is “too” far, runway capacity is reduced. Consistently achieving inter-arrival spacing that is closer to the optimum is an important step in increasing runway capacity for airports that are capacity-limited under instrument approach conditions.

There are many factors that determine the optimum spacing value, some of which are airport-specific. Runway exit geometry, for example, plays a major role in runway occupancy times, which is a key factor in runway capacity. In addition, practical limits are also placed on inter-arrival spacing due to wake turbulence concerns.

Regardless of what the optimum arrival spacing is, consistently working toward that optimum can be problematic. Even with a speed restriction, e.g. “one eight zero to the marker”, flight crews vary in when and how quickly they slow to final approach speed. In the case of ATC, there are several factors that also introduce imprecision. For example, dissimilar speed profiles and inconsistent configuration and speed changes, communication delays, radar data accuracy, the effects of wind gradients, and workload. Regardless of these factors, current ATC operations are very efficient in accommodating these factors and the realization of cockpit-based tools to improve this efficiency will not be trivial.

This approach spacing for instrument approaches (ASIA) application would allow the flight crew to adjust speed for their aircraft via a cockpit-based tool set to achieve to a consistent, preplanned target spacing prior to the lead aircraft landing. Prior to or at the FAF, the flight crew of the trail aircraft will decelerate to their target approach speed and become stabilized prior to landing.

This procedure builds from previous work done on approach spacing. NASA Langley has been developing an approach spacing concept for several years (Williams, 1983, Abbott, 1991, Abbott, 2002, and Oseguera-Lohr, 2002) and a paired approach concept was examined within RTCA (Bone, Mundra, and Olmos, 2001).

This application was originally identified in the Minimum Aviation System Performance Standards (MASPS) for ADS-B and is defined as application D.1.11 (RTCA, 1998). The application is also defined at a high level in an appendix in the Safe Flight 21 Master Plan as Operational Enhancement #3: Improved Terminal Operations in Low Visibility operational application 3.2.2 Approach Spacing for Instrument Approaches (FAA, 2000). Additionally, this builds on several similar concepts including the Enhanced Visual Approaches as defined in RTCA (2000) and Operational Enhancement #3: Improved Terminal Operations in Low Visibility operational application 3.2.1 Approach Spacing for Visual Approaches as defined in the Safe Flight 21 Master Plan (FAA, 2000).

I.1.1.1 Operational Purpose

The purpose of this application is to increase runway throughput by decreasing the variability of arrival spacing and to close up excess spacing between successive arrivals. Currently at busy facilities, ATC does very well at achieving high runway throughput so any tools placed on the flight deck will have to improve upon this efficiency.

I.1.1.2 Domain

The ASIA application is to be conducted in the terminal approach-controlled, surveillance airspace in a single stream approach operation under IFR. The weather minimums for the procedure are not expected to be different than those required of the instrument approach procedure to be followed (e.g., the ILS approach). The procedure could be conducted at airports that are densely populated with air traffic. It is expected that mainly commercial and business aircraft will be equipped to participate in the procedure. ASIA has the potential to be extended beyond just the final approach course in later implementations.

I.1.1.3 Justification

The main benefit from the ASIA is increased capacities at airports during IMC.

I.1.1.4 Maturity and user interest

The FAA Safe Flight 21 program office in coordination with a cargo airline association demonstrated an approach spacing concept in the Fall of 2000 during both VMC and IMC. The demonstration included both an advanced (computed speed command based on aircraft state data and approach geometry) and basic tool set (e.g., range ring, closure rate).

Two ASIA tools have been developed for RTCA SC-186 and Safe Flight 21. One was developed at NASA Langley and the other was developed at MITRE CAASD (see Abbott, 2002 & Wang and Hammer, 2001). As an incentive to accelerate the potential commercialization of this concept, the FAA provided funding for avionics manufactures for the development and flight test of an approach spacing concept in a program called the Test and Evaluation Surveillance and Information System (TESIS). As part of the TESIS contract, a flight test is planned for 2003. Prior to this test, simulations were conducted with flight crews and air traffic controllers at CAASD in a simulation facility (Bone, Helleberg, and Domino, in preparation). NASA Langley completed a high fidelity piloted simulation of their concept in January 2002 and a flight test in the fall of 2002. Additionally, the Langley ASIA interface is planned to be evaluated by flight crews at Atlantic City Airport (ACY). NASA Ames plans to evaluate an ASIA concept as part of their Distributed Air Ground (DAG) concept. A component of this evaluation is to further develop the flight crew interface. These tests and evaluations should provide additional information on the feasibility of the concept and the potential for implementation.

ASIA is in the early stages of development and coordination. The ASIA cost-benefit studies have yet to be conducted.

Depending on the results of research and development, as well as the specific implementation, the CDTI ASIA function may need to interface with systems such as the

FMS, autothrottle, and the navigation display (if not implemented as a stand-alone CDTI). Equipment cost comparisons between CDTI-only and integrated implementations (e.g., implement the ASIA function in the FMS) are needed to determine if an implementation is cost prohibitive. Comparative flight crew workload studies need to be conducted in a realistic operational environment to determine the viability of CDTI-onlyASIA concepts. Specific interface issues should include ASIA-specific information outside of the pilots' primary field of view, supporting alerting functions and the use of aural information relative to current industry alerting standards.

I.1.2 Operational Concept, Roles, and Procedures

I.1.2.1 Concept Description

I.1.2.1.1 System Level Perspective

The ASIA application is an instrument approach procedure involving at least two participating aircraft (i.e., a lead and a trail) and approved instrument approach procedures serving the runway to be used. ATC may pair compatible and eligible aircraft and place them on the final approach course with appropriate IFR separation (e.g., at least 3 nautical miles or 1000 feet). The trail aircraft within the designated pair then conducts the procedure by achieving a defined longitudinal spacing no less than current standard radar separation.[1] The point at which this spacing is achieved is dependent upon the differences in final target speeds of the aircraft and the relative geometries of the participating aircraft. If the final target speed of the lead aircraft is faster than the trail, the minimum spacing may be achieved prior to the lead aircraft crosses the threshold. If the final target speed of the lead aircraft is slower, the minimum spacing may be achieved when the lead aircraft crosses the threshold. The flight crew will use a cockpit-based feature set to perform the spacing task.

Both aircraft in the pair must be properly equipped and have the specific avionics capabilities described in section I.1.3.2.2 to participate in the procedure. As a minimum, the trail aircraft must be equipped with Automatic Dependent Surveillance – Broadcast (ADS-B) with ASIA tools and a Cockpit Display of Traffic Information (CDTI) (stand-alone or on a multi function display) supported by Global Positioning System (GPS). The lead aircraft must also be equipped with ADS-B, a CDTI, and ASIA tools if it is to fly in the tightly controlled ASIA "chain." Initial analysis indicates that if the lead aircraft is not ADS-B equipped and is not conducting the ASIA task that it will reduce the gains expected from the procedure, with a benefit reduction proportional to the ration of unequipped aircraft. This reduction may negate any benefit expected of the procedure unless, potentially, the "unequipped" aircraft is flying a standardized speed profile during the approach.[2]

The ASIA application will require an ability of ATC to determine appropriate equipage of aircraft. The capability to participate in the procedure could be initially indicated in the

[1] It is TBD whether this spacing is received from ATC or it is company procedure.
[2] Such results are based on the fact that the aircraft is not conducting the approach spacing task and not from the quality of TIS-B data from the lead aircraft that could used by a trail aircraft to space on it.

flight plan[3] or displayed as an icon on the controller traffic display. This procedure need to function properly in a mixed equipage environment.

Traffic alert and Collision Avoidance System (TCAS) Resolution Advisories (RAs) will continue to function normally during ASIA operations.

I.1.2.1.2 Arrival and Initial Approach

Prior to entering the terminal area, flight crews will have obtained the destination airport Automated Terminal Information System (ATIS) or Digital ATIS and determined that ASIA in conjunction with the instrument approaches is being used.

Upon arrival in the terminal area, the aircraft are accepted by the feeder controller(s). The feeder controller(s) will know whether the aircraft and flight crew are capable of conducting the procedure. This information will probably be displayed as an icon on the controller traffic display or provided in the remarks section of the flight strip,[4] which would have been provided by the Airline Operation Center (AOC).

If aircraft are appropriately equipped, then on initial contact the feeder controller will instruct the flight crews to expect ASIA. The feeder controller(s) will then issue instructions as necessary and then hand-off the aircraft to the final controller(s). The flight crews are not required to perform any actions for the procedure at this point other than follow routine ATC instructions and brief the approach procedure for their expected runway.

I.1.2.1.3 Establishment on the Final Approach

Once the aircraft are handed off from the feeder controller and when instructed, the flight crews will then check in with the final controller(s) who will issue instructions to the flight crew to establish them on their final approach. The length of the final approach will need to be sufficient to ensure that adequate distance is available for the flight crew of the trail aircraft to make the final required speed adjustments to close to the desired spacing interval relative to the lead aircraft.[5]

As soon as possible, but no later than the intercept to the final approach course, the final controller will identify and communicate to the trail aircraft flight crew which aircraft they will be following.

The flight crew of the trail aircraft must acknowledge the final approach speed of the lead aircraft that is broadcast in the ADS-B message and automatically entered into the system as well as the desired interval. It is expected that the entry of landing speeds will be broadcast in the ADS-B message set; however, if it is not, it could be entered manually through the Control and Display Units (CDUs).[6] Whenever desired, the flight crew of the

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[3] It is possible that a suffix may be used in the next generation terminal automation system.
[4] It is not expected that this information could be in the aircraft suffix, at least in the near term.
[5] Realistic operational constraints will only allow for approximately a 1:20 closure to the desired spacing, i.e., a one mile gap may be eliminated over a 20 mile flight segment.
[6] It is to be determined, whether this exchange of expected landing speeds will take place manually or through a data link. An exchange through the ADS-B data link will require both aircraft to broadcast final approach speed

trail aircraft can select the lead aircraft on their CDTI and arm the ASIA function, which will enable the ASIA tools to appear.[7] The final controller will continue to issue vectors and speed instructions such that the two aircraft are established on their final approach courses.

I.1.2.1.4 Approach Clearance

Once the aircraft are established on final and the final controller has decided to continue the procedure, the final controller will clear the lead aircraft flight crew for the instrument approach. The lead aircraft flight crew will intercept their localizer and fly the approach. This will include maintaining both lateral and vertical guidance, as appropriate.

The trail aircraft flight crew is expected to fly the speed assigned by the final controller until cleared for the approach and the ASIA tool set becomes engaged. The ASIA tool set will likely have certain requirements prior to engaging (e.g., the aircraft ground tracks within the pair must be within 20 degrees of each other). Once the ASIA function has engaged and the speed commands have appeared, the flight crew of the trail aircraft is expected to follow the speed commands provided by the tool. The trail aircraft flight crew now follows the ASIA speed commands to close to the desired longitudinal spacing from the lead aircraft.[8] The ASIA tool set will include a spacing alert which will indicate to the flight crew that they are within the wake vortex boundary from the lead aircraft. It is not expected that this boundary will be exceeded except under unusual situations since this distance will be inside any chosen spacing criteria and ATC maintains wake and separation responsibility throughout the procedure. If the alert is triggered, the flight crew is required to contact ATC.

At this point, the final controller has cleared both aircraft for their approaches and has advised them to contract the tower at the required position. Additionally, the flight crew of the trail aircraft is using the ASIA tools to fly the procedure. The proposed set of CDTI display symbols could include speed commands as well as other CDTI position indication cues. A spacing tool would provide speed recommendations for the trail aircraft that are used to achieve the desired spacing prior to the lead aircraft landing.

Once the trail aircraft reaches the FAF, the active spacing task is discontinued and the trail aircraft flight crew will decelerate to and maintain its final approach speed (V_{ref} plus any necessary additions) to a normal landing.[9] To reduce flight crew workload and to assure a stable final approach speed, the ASIA tool could provide a transition to the final approach speed, with appropriate display enunciation. Additionally, since the deceleration rate to the final approach speed is critical for optimizing the final approach performance, as well as assuring a stable final approach segment, the ASIA tool should provide a scheduled, nominal deceleration to the final approach speed.

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information, and will require the aircraft to activate the procedure and identify the other aircraft on the display. Whether this entry will be into the FMS CDU or a separate CDU is yet to be determined.

[7] At this time, it is expected that these tools will simply be CDTI tools; however, they may include certain flight control tools in order to reduce the workload.

[8] If the lead aircraft executes a missed approach prior to the following aircraft reaching the FAF, the ASIA tool should at revert to a command of the nominal speed.

[9] If the lead aircraft executes a missed approach after the trail aircraft reaches the FAF, the ASIA tool will continue to provide a nominal deceleration to the following aircraft's final approach speed.

I.1.2.1.5 Procedures and Responsibilities

I.1.2.1.5.1 Air Traffic Control

The **feeder** controllers are expected to:

1. Identify aircraft capable of conducting ASIA approaches;
2. Advise the appropriately equipped aircraft to expect ASIA (if necessary, request the planned target speed);
3. Vector aircraft for approaches;
4. Handoff aircraft to the final controller

The **final** controllers are expected to:

1. Identify aircraft pairs;
2. Advise the trail aircraft flight crew of the flight identification (if necessary, the planned final approach speed of the lead aircraft, and potentially the spacing interval);
3. Establish aircraft pairs on the approach with at least the standard IFR separation at predetermined position on final approach course;
4. Clear lead aircraft for the approach;
5. Clear trail aircraft for the approach via ASIA; and
6. Advise the flight crews of both aircraft to contact the tower.

As with other approach operations, pilots will need to be informed that ASIA operations are being conducted. This is expected to occur through the ATIS.

I.1.2.1.5.2 Flight Crew

Prior to ATC advising the flight crews of the lead aircraft for conducting ASIA, the flight crew is expected to:

1. Obtain the destination airport's ATIS to determine if ASIA is in use;
2. Advise the feeder controller if unable to conduct the ASIA;
3. Enter for broadcast, the ownship final approach speed (V_{ref} plus any necessary additions);
4. If this information is not broadcast on the ADS-B message, inform the feeder controller of final approach speed;
5. Conduct appropriate approach briefs;

6. Contact the final controller;

When ATC has advised the flight crews of the lead aircraft for conducting ASIA, the flight crew of the trail aircraft is expected to:

1. Identify the lead aircraft on the CDTI;
2. Distinguish / select the lead aircraft from other traffic on the CDTI (easier due to ATC use of aircraft identification);
3. Input the ASIA information for the ASIA tool as necessary (e.g., final approach speeds, desired spacing interval, minimum spacing interval)
4. Conduct the approach brief (if not already accomplished);
5. Intercept the lateral guidance
6. "ARM" ASIA (if tool set requires such a function);
7. When ASIA becomes enabled, follow the speed commands provided to achieve the spacing interval;
8. If the wake boundary spacing alert is triggered, the flight crew must contact ATC;
9. If appropriate, intercept the vertical approach path;
10. Deceleration to the planned approach speed inside the FAF; and
11. Fly the planned final approach speed inside the FAF.

The flight crew of the trail aircraft should notify ATC immediately of any degradation of aircraft or navigation systems that may lead to their inability to perform the procedure. Flight crews should also notify ATC if at any point they are unable to continue the approach and need breakout instructions. The flight crew of either aircraft should immediately inform ATC if a change in planned final approach speed is necessary.

I.1.2.2 Airline Operations

The AOC will be responsible for assuring that the flight plans indicate whether or not the aircraft and flight crew are qualified to conduct the procedure. It is expected that this will be done in the remarks section of the flight plan. A future capability may allow this to be noted in the aircraft suffix or to be displayed as an icon on the controller traffic display.

I.1.2.3 Flight Service Stations

Flight service stations are not expected to be directly involved in this application.

I.1.2.4 Proposed New Phraseology

Communications will involve the use of flight identification and may include the transmission of the appropriate spacing interval for the trail aircraft. It is yet to be determined if flight identification can be used with existing phraseology. This question is also being addressed during the development of the concept.

I.1.2.5 Aircraft Separation / Spacing Criteria

It is not expected that this application will reduce current separation minima. The spacing to maintain behind the lead aircraft will be greater than any radar separations (including wake turbulence applications). How this spacing is determined is to be defined. The ASIA tool set will include a spacing alert which will indicate to the flight crew that they are within the wake vortex boundary from the lead aircraft. If the alert is triggered, the flight crew is required to contact ATC.

I.1.2.6 Sample Scenarios

The following example describes the procedure as it may be applied at Airtown (KAIR) airport on runway 16. In this sample scenario, TRL 44 and LED 525 are the aircraft arriving for the approach. Both aircraft are Boeing 737s and have ADS-B, CDTIs, and are ASIA capable. TRL 44 is arriving from the southwest and LED 525 is arriving from the southeast. The surface winds are from 190 degrees at 10 knots (see Figure **I-1**). The scenario will be narrated from the perspective of the flight crew of TRL 44.

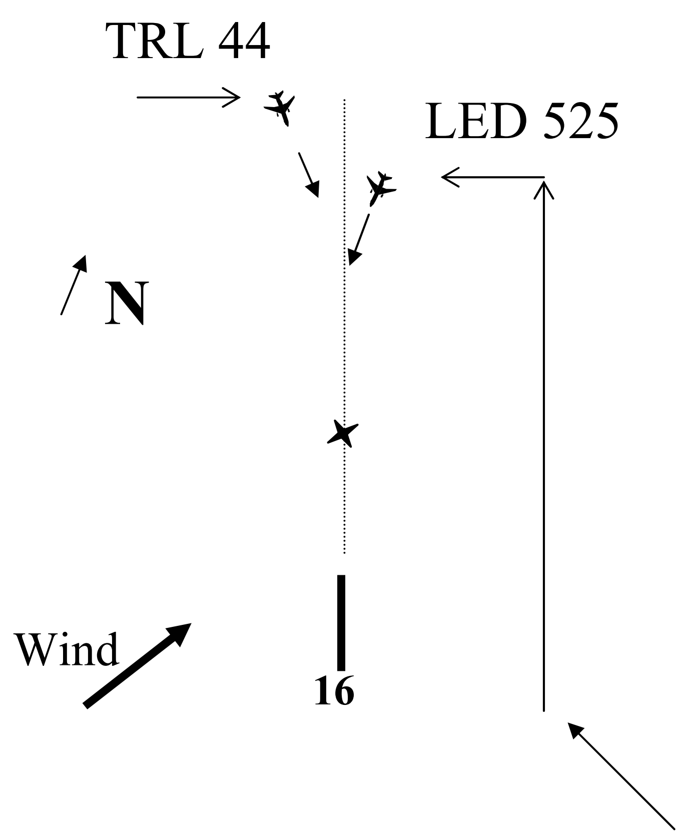

Figure I-1 KAIR ASIA Plan View

Prior to arriving in the KAIR area, both aircraft flight crews are notified by the KAIR ATIS Delta that ASIA operations are being conducted. Since both aircraft are properly equipped and both flight crews are properly trained in the procedure, they are able to conduct the procedure. These flight crews then brief the approach to include the ASIA procedure. At this time, the flight crews also enter the preliminary ASIA data into the CDTI (e.g., surface winds).

As the aircraft approach the KAIR area, the approach control traffic management unit (TMU) determines that TRL 44 and LED 525 and other aircraft can conduct the ASIA task based on equipage and their expected approach sequencing. The TMU then adjusts the arrival rate accordingly.

As TRL 44 and LED 525 approach the terminal area, the ARTCC executes the hand-offs and instructs the flight crews to contact approach control. The aircraft then check in on the assigned frequency with Approach Control. The West and East Feeder Controllers will tell TRL 44 and LED 525, respectively, to expect the ASIA approach, along with any necessary instructions.

- TRL 44: "Airtown Approach, Trail four four level at one zero thousand with information Delta."
- West Feeder Controller: "Trail four four, Airtown Approach. Radar contact. Expect ASIA Runway 16. Traffic to follow will be lead five two five, target distance three and one half miles."[10]
- TRL 44: "Trail four four expect ASIA Runway one six. Traffic to follow will be lead five two five, target distance three and one half miles"
- LED 525: "Airtown Approach, Lead five twenty five at one zero thousand with Delta."
- East Feeder Controller: "Lead five twenty five, Airtown Approach. Radar contact. Expect ASIA Runway one six."
- LED 525: "Lead five twenty five expect ASIA Runway one six."

The feeder controllers issue vectors and speed instructions, as necessary, to the aircraft, hand off to the approach control final controller, and instruct the flight crew to contact the final controller. As soon as the flight crews have determined their final approach speed, Vapp (Vref plus any necessary corrections) and have the available time, they will enter that number in the CDU for broadcast via ADS-B (this is in the message set being transmitted to other aircraft). In this case, the final approach speeds for LED 525 and TRL 44 are 135 and 145 knots, respectively. The final controllers continue to issue altitude and heading instructions to both aircraft as necessary to establish them on the final approach course, level, with standard IFR separation.

As the flight crews are receiving vectors, the flight crew of TRL 44 selects LED 525 on the CDTI. Once the aircraft is selected, additional information is provided to the flight crew in a datablock. This information includes LED 525's ground speed, range, flight identification, and weight category (see Figure I-2). The fact that LED 525 is selected on the CDTI is passed through the FMC so that other on-board systems may access that information.

[10] The means by which this information is conveyed to the flight crew is TBD.

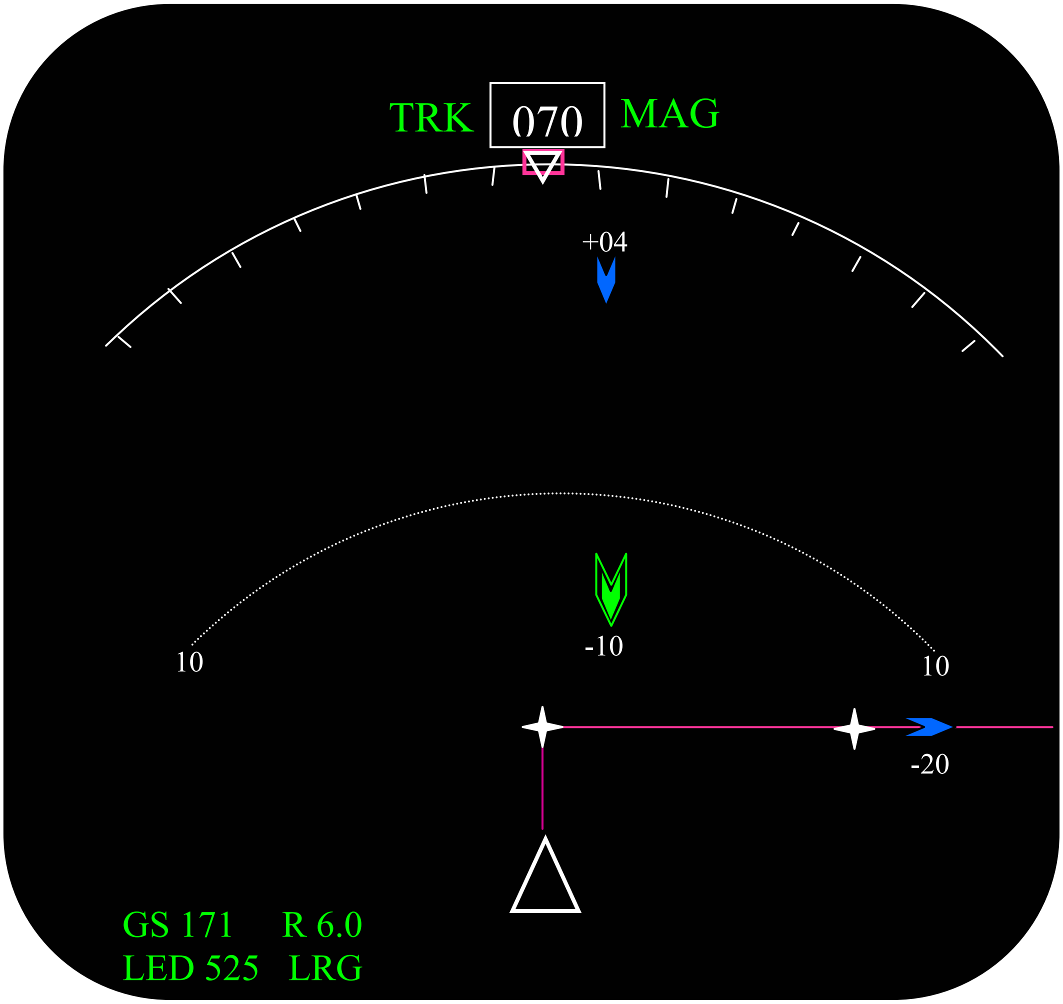

Figure I-2 Cockpit Display of Traffic Information (CDTI) with Aircraft Selected

At this point the flight crew of TRL 44 would interact with the CDU by entering or confirming the necessary information for the ASIA procedure (see Figure **I-3**). This interaction includes confirming the expected lead aircraft identification and that it has reported a final approach speed. For TRL 44, this confirmation includes the lead aircraft identification of LED 525 and 135 knots. They will also confirm their own final approach speed. Since the ownship final approach speed was previously entered and the FMS had knowledge of the selected aircraft and its broadcast final approach speed, this information is automatically entered into the associated fields. The flight crew must enter the target spacing interval though.[11] The flight crew will then arm the ASIA function.

[11] How this target spacing interval is determined and conveyed to the flight crew is TBD.

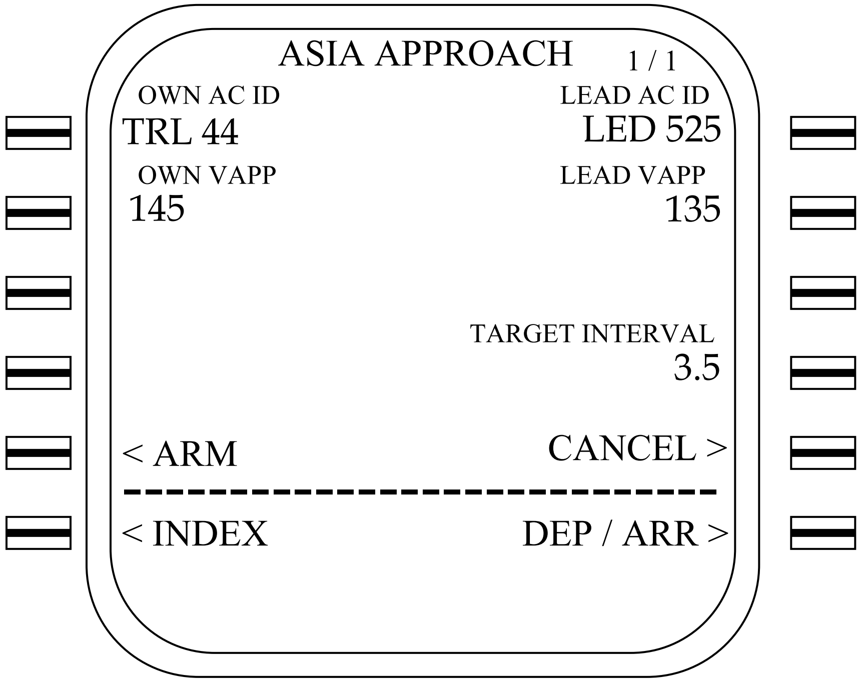

Figure I-3 **Completed Sample ASIA Control and Display Unit (CDU) Page**

The following communications then occurs prior to intercepting final.

- Runway 16 Final Controller: "Lead five twenty five, eight miles from FFAFF. Turn left heading one nine zero. Maintain four thousand until established on the localizer. Cleared ILS runway one six. Maintain one seven zero knots till FFAFF. Contact tower at FFAFF."
- Flight crew LED 525: "Lead five twenty five, left to one nine zero. Maintain four thousand till established. Maintain one seventy knots till FFAFF. Cleared ILS one six. Contact tower at FFAFF."
- After LED 525 has been cleared for ILS to runway 16, the flight crew follows the localizer and glide slope (upon interception), and flies their instructed speed and then their final approach speed after the FAF to a normal landing.
- Runway 16 Final Controller: "Trail four four, thirteen miles from FFAFF, turn right heading one three zero. Maintain five thousand till established. Cleared ASIA runway one six behind Lead five twenty five."
- Flight crew TRL 44: "Trail four four, turn right heading one three zero. Maintain five thousand till established. Cleared ASIA one six behind Lead five twenty five."

Since the flight crew of TRL 44 has already selected and confirmed the information for LED 525 no further flight crew actions are necessary. If another aircraft was instead the lead, they would need to select that aircraft and make the appropriate entries and confirmations of information.

After TRL 44 intercepts the localizer, the ASIA function is able to become engaged. When the ASIA function transitions from armed to engaged on TRL 44, and the speed cues appear, the flight crew will begin the spacing task by following the ASIA speed commands. For example, when the hollow cyan commanded speed bug appears on the PFD airspeed tape it indicates that the required speed is 200 knots (see Figure **I-4**) since there is still some distance to close prior to achieving the target distance. The flight crew then matches the magenta autothrottle speed bug with the commanded speed bug to achieve the commanded speed. The flight crew continues these speed reductions, as necessary, along final approach. If at any point the wake boundary spacing alert is triggered, the flight crew must determine the appropriate course of action based on the given conditions. It is not expected that this boundary will be exceeded except under unusual situations since this distance will be inside any chosen spacing criteria and ATC maintains wake and separation responsibility throughout the procedure.

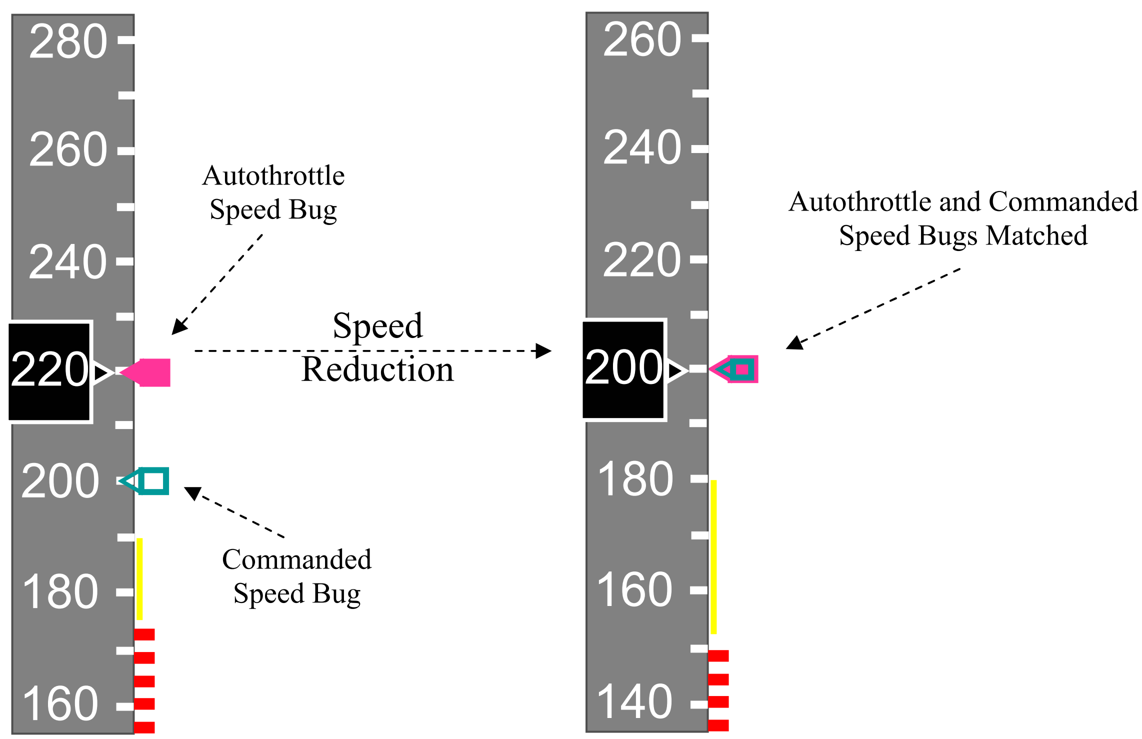

Figure I-4 Sample ASIA Speed Cues on Airspeed Tape

The flight crew continues to track the localizer, intercepts the glide slope, and flies the ASIA speed commands to the Final Approach Fix (FAF). At the FAF, the commanded speed bug is placed at the final approach speed entered by the flight crew in the CDU and the flight crew no longer actively maintains ASIA spacing.[12] They slow to their final approach speed and continue to a normal landing.

[12] Optionally, the ASIA speed command can provide a scheduled deceleration to the final approach speed, thus reducing crew workload.

I.1.3 Requirements

I.1.3.1 Display & Interface / Functional

{This section still needs finalization once CDTI section of ASA MASPS is complete}

The ASIA CDTI features are list in Table I-1 (for all potential features see Table ???). The features labeled as "**Required**" in the need column are believed to be necessary to perform the ASIA application. Those labeled as "Desirable" are not required to perform the procedure but would increase the utility of the operation.

Table I-1 ASIA Display Requirements

Display Elements	Display Range Reference	R
	Track Up / Heading Up / Course Up Map Mode	R
	Target Selection	R
	Algorithm commanded speed indication	R[1]
Symbols	Own-Ship	R
	Traffic	R
	Selected Target	R
Traffic Elements	2D Positioning Information	R
	Altitude (Relative or Absolute)	R
	Identification[2]	R
Selected Traffic Elements	Highlighting	R
	Identification	R
	Category	R
	Ground Speed	D
	Range	D
	Closure Rate	D
	Off-Display Selected Target Relative Bearing	D
Alerting Elements	Visual Alert	R?
	Aural Alert	R?

R = Required
D= Desirable

Notes:

1. *This information could be placed elsewhere in the cockpit such as on the Primary Flight Display.*

2. *If required, should be available for display but not necessarily continually displayed.*

The flight crew will need the following capabilities.

1. View the flight identification, horizontal position, and altitude of surrounding traffic;

2. Select and highlight a specific target on the display;

3. Select the ASIA function;

4. Input and / or confirm the final approach speed for own aircraft and input and / or confirm the other aircraft flight identification and final approach speed and the desired spacing interval;

5. Arm the ASIA tool (if the tool set requires such a function);

6. Determine that the approach tool is operating normally;

7. Display lead aircraft information to assist in monitoring the longitudinal distance with the lead aircraft (e.g., ground speed, range read-out);

8. Determine / view the lead aircraft position for a safe interval;

9. View and utilize the ASIA tool (e.g., speed guidance) to assist in acquiring the desired spacing interval;

10. Determine when own ship has achieved the desired spacing interval, when own ship is approaching the minimum spacing interval (which may be different than the desired spacing interval), and at a breakout point; and

11. Determine when the spacing task is to be discontinued.

Different forms of alerting may also be a requirement for the CDTI. Required alerts include a spacing alert which will indicate to the flight crew that they are within the wake vortex boundary from the lead aircraft as well as a surveillance alert indicating degraded surveillance information. Another alert could be an alert indicating that the minimum spacing will be broken at some point in the near future. An alert may also be required that indicates a maximum spacing which the flight crew should not exceed. These alerts may need to be both visual and aural. The alerting requirements shall conform to current industry standards and practices.

The controller will need the capability to:

1. Identify appropriately equipped aircraft (e.g., traffic display icon, flight strips, datablock).

The controller may need the capability to:

1. Identify aircraft that are not conforming to the ASIA clearance (via an ADS-B conformance message from the non-conforming aircraft).

I.1.3.2 Infrastructure Requirements

I.1.3.2.1 Ground ATC

A capability for designating appropriate equipage by aircraft to ATC will be required.

TIS-B infrastructure is unnecessary for the procedure since its use is not expected to be beneficial.

I.1.3.2.2 Flight Deck

The ASIA application requires that aircraft to be paired are equipped with an appropriate level of ADS-B and CDTI. These include the capabilities to:

1. Transmit appropriate position;
2. Transmit final approach speed data;[13]
3. Transmit weight class or aircraft category data
4. Access the appropriate ASIA tools;
5. Input certain parameters; and
6. Select and activate the ASIA procedure.

Depending on the tool set used and the workload required, coupling the speed commands to the autothrottle may be required. Such a system has been analyzed previously and flight crews believed it to be a possible implementation (Bone, et al. 2000). However, even though it reduces pilot workload, it could be an expensive implementation.

It may be that an FMS will act as an interface to the CDTI so that the flight crew is able to enter the necessary parameters (e.g., final approach speeds). Assuming that the aircraft has an existing autothrottle and given this FMS assumption, the specific issue of autothrottle expense, noted above, may be eliminated if the ASIA tool is implemented in the FMS. In this implementation, the ASIA speed mode would become just another FMS speed mode.

I.1.3.2.3 Airlines Operations Center & Flight Service Stations (if applicable)

There are no infrastructure requirements for the AOC.

I.1.4 Other Considerations

I.1.4.1 Relationship to Other Programs and Future Enhancements

The FAA Safe Flight 21 program office in coordination with a cargo airline association demonstrated an approach spacing concept in the Fall of 2000 (see FAA, 2001, & Olmos, Bone, Domino, 2001).

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[13] It may be possible to accomplish this procedurally.

Work previously conducted on a Paired Approach spacing task to closely spaced parallel runways aided in the development procedures and the spacing tool set of this application (see Bone, Mundra, Olmos, 2001).

I.1.4.2 Training Requirements

A candidate flight crew training syllabus is provided in Oseguera-Lohr, 2002, with the training mimicking traditional airline training for a new procedure. The training footprint was approximately two hours which included approximately one hour of simulator training. The training was reported to be adequate by the test subjects. However, final training requirements will need to be determined prior to implementation.

I.1.4.3 Other Issues

I.1.4.3.1 Issue: Is a CDTI Outside the Primary Field of View or Information on the Navigation Display Adequate for Approach Spacing in Instrument Conditions?

Does the ASIA information needed to be integrated into the pilots' primary flight display? Is a spacing tool, outside of the pilots' primary field of view, adequate for this application? This issue is likely related to the ASIA tool set.

Priority: High
Resolution Method: Analysis, flight simulation, flight test,
Status: Open
Resolution: [*Detailed discussion*]

I.1.4.3.2 Issue: What is the Minimum Spacing for the Flight Crew to Achieve?

The minimum spacing to be achieved by the flight crew is directly related to the issue of who is responsible for separation and is likely related to the ASIA tool set.

Priority: High
Resolution Method: [*e.g., discussion, literature search, flight simulation, flight test, analysis, modeling]*
Status: [*e.g., open, closed*]
Resolution: [*Detailed discussion*]

I.1.4.3.3 Issue: Issuance of Spacing Instruction

Who will determine the required spacing for the flight crew to maintain? Will ATC provide the spacing instruction to the flight crew? What are the issues if ATC is to provide the spacing? What are the issues if the company or the pilot determines the desired spacing?

Priority: High
Resolution Method: [*e.g., discussion, literature search, flight simulation, flight test, analysis, modeling]*
Status: [*e.g., open, closed*]
Resolution: [*Detailed discussion*]

I.1.4.3.4 Issue: FMS Equipage

Do all aircraft need to be FMS equipped? Does equipage depend on conditions, i.e., IMC vs. VMC? The algorithm may need aircraft performance speed ranges for commanded speed limits. If an FMS is not used, how will the flight crew interface with the CDTI?

Priority:
Resolution Method: [*e.g., discussion, literature search, flight simulation, flight test, analysis, modeling]*
Status: [*e.g., open, closed*]
Resolution: [Detailed discussion]

I.1.4.3.5 Issue: What Kind of Speed Commands Would be Acceptable Operationally

Are only speed decreases acceptable? Are both speed increases and speed decreases operationally acceptable? What are the minimum and maximum speed changes operationally acceptable (e.g., 1 knot increments, 5 know increments)?

Priority:
Resolution Method: [*e.g., discussion, literature search, flight simulation, flight test, analysis, modeling]*
Status: [*e.g., open, closed*]
Resolution: [*Detailed discussion*]

I.1.4.3.6 Issue: What if the Desired Spacing Goal Can Not be Achieved?

If the desired minimum spacing goal cannot be achieved, what should be the proper behavior of the approach spacing tool set? Should it continue to give speed commands to allow for some closure?

Priority:
Resolution Method: [*e.g., discussion, literature search, flight simulation, flight test, analysis, modeling]*
Status: [*e.g., open, closed*]
Resolution: [*Detailed discussion*]

I.1.4.3.7 Issue: Is the Final Approach Speed Transmitted in the ADS-B Message Set?

If not, ATC transmit?

Priority:
Resolution Method: [*e.g., discussion, literature search, flight simulation, flight test, analysis, modeling]*
Status: [*e.g., open, closed*]
Resolution: [*Detailed discussion*]

I.1.4.3.8 Issue: Should a Non-Conformance Variable be Transmitted in the ADS-B Message Set?

Would a non-conformance message with appropriate ATC display enhance ATC acceptability and usability of this concept?

Priority:
Resolution Method: [*e.g., discussion, literature search, flight simulation, flight test, analysis, modeling]*
Status: [*e.g., open, closed*]

Resolution: [*Detailed discussion*]

I.1.4.3.9 Issue: Environment Input Requirements

What environmental inputs are necessary for tool accuracy, e.g., winds, temperature? Are required inputs different for VMC and IMC procedure?

Winds: How are the winds measured and set to aircraft? Are surface winds sufficient? What are the effects on alerting and false alarm rates?

Priority:
Resolution Method: [*e.g., discussion, literature search, flight simulation, flight test, analysis, modeling]*
Status: [*e.g, open, closed*]
Resolution: [*Detailed discussion*]

I.2 Requirements Analysis for Approach Spacing for Instrument Approaches (ASIA)

Working from the OSED contained in Section D.1.1, we now proceed to derive requirements for implementation of ASIA. The requirements analysis process proceeds in several stages; first, we develop requirements derived from the OSED that have implications for the OHA (Operational Hazard Assessment). The requirements are listed in Table I-2. Each requirement has an associated unique designator for traceability purposes. After these requirements are listed, we proceed to develop phases and process for ASIA (§I.1.1), then conduct the operational hazard analysis (I.2.2.1) followed by a failure modes analysis (§I.2.2.2), and a fault-tree analysis (§I.2.2.3). Requirements that are necessary to support the intended function of the application are contained in §I.2.3. Finally, §I.2.4 contains a summary of the requirements for ASIA.

The requirements and assumptions from the OSED have been classified into the following categories:

- Operating environment (assumption related to the context of operations), referenced as OExx.
- Operational objective (intended function), referenced as OOxx.
- Operational requirement for the ground segment, referenced as RGxx. Such requirements are to be related to existing ATC procedures and equipment as far as possible; new requirements are derived from the OHA
- Operational requirement for the airborne segment, referenced as RAxx. Such requirements should be related to existing regulations for aircraft equipage or procedures as far as possible. New requirements are derived from the OHA. However, there may be instances when a service is only intended to specific categories of aircraft.
- Selection of technology, referenced as STxx. Allocation for a requirement is already based on an arbitrary technology. Those requirements are kept to a minimum and are generally delayed down to the Allocation of Safety and Operational Requirements phase or even as proposed means of compliance.

Table I-2 Operational Requirements and Assumptions Summary

REQ No.	Description	Traceability to paragraph in operations description	Category
OE1	Terminal approach-controlled environment in radar controlled airspace	I.1.1.2	operating environment
OE2	Single stream approach operation under IFR	I.1.1.2	operating environment
OE3	TCAS RA and procedures remain unchanged	I.1.2.1.1	operating environment
OE4	The capability to participate in the procedure will initially be indicated in the flight plan	I.1.2.1.1	operating environment
OO1	The ASIA application is an instrument approach procedure involving at least two participating aircraft (i.e., a lead and a trail) and approved instrument approach procedures serving the runways to be used.	I.1.2.1.1	operational objective (intended function)
OO2	The point at which this spacing is achieved will depend upon the differences in final target speeds of the pairs of aircraft involved. However, the minimum wake vortex separation standards are to be maintained throughout the approach.	I.1.2.1.1	operational objective (intended function)
OO3	ASIA application will be designed to function properly in a mixed equipage environment	I.1.2.1.1	operational objective (intended function)
OO4	The length of the final approach will need to be sufficient to ensure adequate distance is available …	I.1.2.1.1	operational objective (intended function)
OO5	Once the aircraft are established on final and the final controller(s) has decided to continue the procedure, the final controller will clear lead aircraft flight crew for ILS for the runway	I.1.2.1.1	operational objective (intended function)
RG1	ATC must pair compatible and eligible aircraft and place them on the final approach course with required separation	I.1.2.1.1	Operational requirement for ground segment

Table I-2 Operational Requirements and Assumptions Summary (continued)

REQ No.	Description	Traceability to paragraph in operations description	Category
RG2	ATC to determine appropriate equipage of aircraft The feeder controller(s) will know whether the aircraft and flight crew are capable of conducting the procedure by the information provided in the remarks section of the flight strip	I.1.2.1.1	Operational requirement for ground segment
RG3	On initial contact the feeder controller will instruct the flight crews to expect ASIA	I.1.2.1.1	Operational requirement for ground segment
RG4	As soon as possible, but no later than the intercept to the final approach course, the final controller(s) will identify and communicate to the trail aircraft flight crew which aircraft they will be following and its final approach speed	I.1.2.1.3	Operational requirement for ground segment
RG5	Operational procedures for ATC	I.1.2.1.4	Operational requirement for ground segment
RA1	Commercial and business jets (FAR/JAR25 and FAR/JAR23)	I.1.1.2	Operational requirement for airborne segment
RA2	Both aircraft in pair must be properly equipped	I.1.1.2	Operational requirement for airborne segment
RA3	Prior to entering the terminal area, flight crews will have listened to the destination airport ATIS and determined that ASIA in conjunction with the instrument approaches is being used	I.1.2.1.2	Operational requirement for airborne segment
RA4	The trail aircraft flight crew is expected to fly the speed assigned by the final controller until cleared for the approach and the ASIA tool set becomes engaged.	I.1.2.1.4	Operational requirement for airborne segment
RA5	The system will not issue speed commands until the flight crew enters their planned final approach speed.	I.1.2.1.4	
RA6	Before issuing speed commands provided by ASIA algorithm, the system will provide a separation alert to the flight crew if the entered value of the separation is less than that required by wake vortex minima.	I.1.2.1.4	Operational requirement for airborne segment

Table I-2 Operational Requirements and Assumptions Summary (continued)

REQ No.	Description	Traceability to paragraph in operations description	Category
RA7	Flight crew of trail a/c expected to follow speed commands of ASIA algorithm Operational procedures for flight crews and airlines operations	I.1.2.1.4 I.1.2.2	Operational requirement for airborne segment
ST1	At least the trail aircraft must be equipped with ADS-B and ASIA display supported by GPS (or required navigation accuracy, integrity and availability)	I.1.2.1.4	selection of technology

I.2.1 ASIA Phases and Processes

Operations supporting the ASIA approach spacing application described in sections X.X can be grouped into four distinct phases (P1 – P4); these are:

- P1 Setup for approach spacing procedure
- P2 Clear for approach spacing procedure
- P3 Conduct approach spacing procedure
- P4 Complete approach spacing procedure.

These phases are illustrated in the activity diagram shown in Figure I-5 below, along with the specific responsibilities of both the flight crews and air traffic control.

Phases are further subdivided into "processes," that are shown in the process diagram of Figure I-6. A large rectangular block depicts each phase; the smaller rectangular blocks represent the processes of each phase. The processes are considered "atomic" in that careful analysis of failures of the processes is expected to assure the safety of the operation.

The setup phase (P1) consists of 8 processes, 7 of which are directly linked. The "ATC Assure Separation" process is a continuous process, based on ATC surveillance using secondary radar, and is independent of the ADS-B surveillance used in the air-to-air parts of the operation.

Process 1.1 (P1.1) consists of ATC providing typical vectors to an ILS approach. The flight crew prepares as usual for final approach and landing, and performs the additional step of entering own ship's planned final approach speed into the approach spacing system through the CDTI user interface (P1.2).

In P1.3 ATC provides a call out for the traffic to be followed (TTF) by the flight crew. The traffic must be identified and selected on the CDTI by the flight crew (P1.4*)*. The flight crew then confirms approach parameters. Once the traffic is identified the flight crew notifies ATC via an acquisition message (P1.5). If for some reason the traffic can not be identified on the CDTI, the flight crew notifies ATC of an unsuccessful search (P1.6). An unsuccessful search is assumed to result in another attempt through processes P1.3, P1.4, and P1.5. If the search continues to be unsuccessful, it is assumed that the approach spacing procedure is abandoned, and that normal ATC guidance is provided. This is indicated by the dashed line leading to "revert to standard ATC ops."

If the identification process is successful, the crew will be provided with a spacing target by ATC or by an automated lookup based on the weight category of own ship and the lead ship (P1.7).

At this point in the procedure, ATC will provide a clearance to the flight crew to proceed (Phase 2). The flight crew then enters the "conduct approach spacing phase," (P3), and begins to follow speed guidance cues provided on the CDTI (P3.1). Meanwhile, ATC is expected to continue monitoring the aircraft approach to determine if an unsafe situation is developing (P3.2). The flight crew simultaneously monitors the situation and responds to any alerts issued by the approach spacing system.

If a separation below the minimum wake vortex separation standards is detected by the airborne approach spacing system, an alert is issued to the flight crew and a breakout command is issued. Likewise, if ATC detects an unsafe situation, a command to breakout may be issued by a controller (P3.3). Based on commands from either ASIA or ATC, the flight crew performs a breakout maneuver (P3.4).

If the flight crew follows the guidance provided by the approach spacing system, and that guidance is within tolerance, appropriate spacing will be maintained through the approach, and phase 4 of the operation, completing the procedure, can proceed. In this case, a clearance for landing is issued by ATC (P4.1), followed by the crew flying the approach at the final approach speed and landing (P4.2). As part of phase 4, ASIA continues to monitor separation (P4.4) and if inadequate spacing is detected, the crew is alerted and may execute a missed approach (P4.3). Note that no active guidance is issued by the approach spacing system after the final approach fix; a command to decelerate to the final approach speed is given at the final approach fix, and it is expected that the flight crew will follow their planned final approach speed through the remainder of the approach..(Once the flight crew is at the final approach fix small speed changes may be made by the flight crew at their discretion).

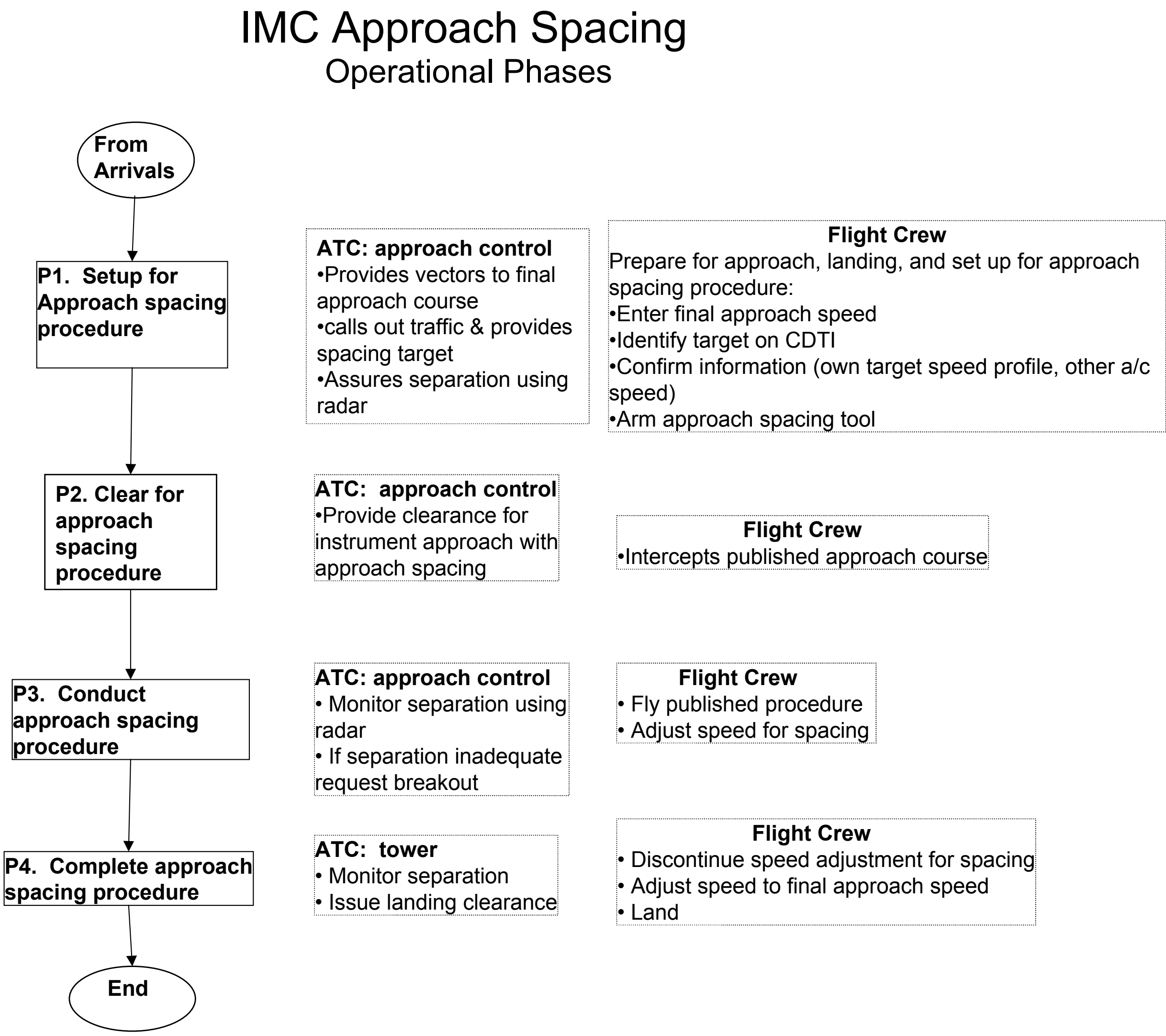

Figure I-5 Approach Spacing Phases

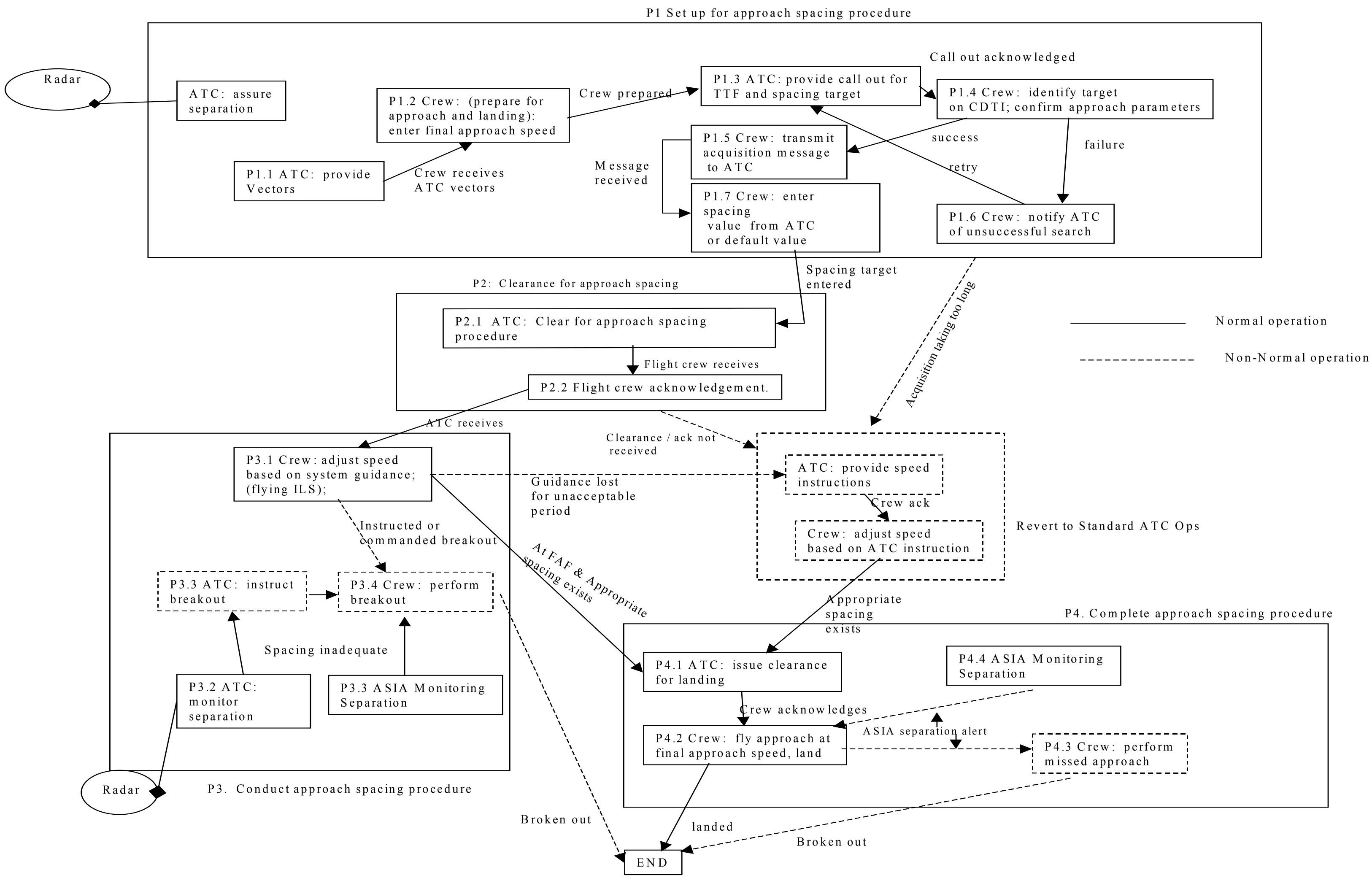

Figure I-6 Approach Spacing Processes

I.2.2 Hazard and Safety Analysis

I.2.2.1 Operational Hazard Analysis (OHA)

The hazard analysis for ASIA consists primarily of a careful examination of the phase and process diagrams illustrated above in Figure I-5 and Figure I-6. Hazards are identified for each process depicted in Figure I-6 by posing two hypotheses:

1. The process does not complete normally.

2. The process completes based on erroneous information or assumptions.

These two hypotheses form the basis of the hazard analysis that is presented in Table I-3 below. Each hazard is identified with a unique number relating to the phase and process to enable reference.

The most significant hazards with ASIA are those that related to the identification of the lead aircraft as well as speed and those pertaining to phase 3, where flight crews are conducting the ASIA procedure. Consequently, these hazards drive the analysis requirements.

Table I-3 contains the following columns:

- Phase (corresponding to the phases in Figure I-5).
- Process (corresponding to the processes identified in Figure I-6).
- OH number: This column lists the numeric designator that was assigned to each hazard. The form of the hazard identifier is: H.Phase.process.hazard_number.
- Operational Hazard description.
- Potential Operational Consequence: The operational effect of encountering the identified hazard. Identifying the potential consequence (effect, failure condition) aids in determining the appropriate hazard class. Note, however, that a consequence of a hazard is not necessarily immediate. A series of events and combinations of hazards is normally required for a consequence to ultimately occur. This series of events and hazards are identified through a fault tree analysis that is documented in §I.2.2.3 below. This safety analysis also includes, as a potential mitigation, the intervention of ATC; ATC is expected to intervene if necessary to help prevent a mid-air collision.
- Environmental considerations (from Table I-2): These are environmental and procedural considerations, assumptions, expectations, and requirements from the OSED that play a role in the operational hazard classification.
- Hazard Class: The classification of the operational hazards according to the severity of their identified consequences (effects, failure conditions) per the classification scheme. The class indicated corresponds to the worst possible effect. For example, impact of "erroneous approach speed" has been determined to potentially lead to wake vortex encounter (class 2 hazard) or mid-air collision with lead aircraft (class 1 hazard). Classification for this failure case is documented with the most severe consequence: class 1.

The objectives and requirements derived from the OHA for each hazard with a classification of 3 or higher (more hazardous) are further assessed as part of the ASOR process.

Some of the hazards have no further safety requirements and are not analyzed or allocated herein. The hazards that are not specifically related to the new services considered in this document and that remain unchanged from current operational procedures are not assessed; these hazard classification for these hazards is designated N/A (not applicable), since their safety assessment already forms part of the current operations and is subject to continuous monitoring. The hazards that were classified as 5 have no safety impact and are not further analyzed. Hazards that were classified as 4 are allocated “Minimum” requirements. Per AMJ 25.1309 §8b(2), “if the hazard assessment, based on experienced engineering judgment, determines that system malfunctions cannot result in worse than Minor Failure Conditions, or affect other airworthiness-related functions, no further safety analysis is necessary to show compliance with JAR 25.1309”.

Per AMJ 25.1309, no further analysis is necessary when the allocated requirements are ”Minimum”. However, in this end-to-end context, “system” should be interpreted as the “end-to-end system” encompassing both airborne and ground systems, and their supporting networks. For the airborne system, per RTCA DO-178B/Eurocae ED-12B §2.2.2, this safety requirement implies that the contribution of software components to these potential failure conditions must be mitigated by at least a software level D requirement. Similarly, this “minimum” safety objective applies to the ground system and the supporting network.

Table I-3 Operational Hazard Analysis Results

Phase	Process	Hazard ID	Operational Hazard Description	Potential Operational Consequence	Environmental Considerations (from Table I-2)	Hazard Class
P1: Setup	P1.1 (ATC provides vectors)	H1.1.1	No vectors provided by ATC	Identical to current operational procedure	N/A	N/A
	P1.2 Crew: prepare for approach and landing; enter final approach speed	H1.2.1	No approach speed entered	Procedures accommodate mixed equipage. Effect is equivalent to ASIA function not available with potential slight increase in workload	OE1/2 OO2/3 RG5 RA6/7	4
		H1.2.2	Erroneous approach speed entered	Wake vortex encounter Mid-air collision with lead a/c	RA1/2/4/6/7	1
	P1.3 ATC: provide callout for traffic to follow	H1.3.1	Erroneous traffic call out	Wake vortex encounter Mid-air collision with lead a/c	RG5 RA7	1
		H1.3.2	Loss of traffic call out	Environment ensures that this is equivalent to loss of ASIA (H1.2.1)	OE1/2 OO2/3 RG5 RA6/7	4
	P1.4 Crew: Identify target on CDTI	H1.4.1	Lead target traffic not found by crew	Environment ensures that this is equivalent to loss of ASIA (H1.2.1)	OE1/2 OO2/3 RG5 RA1/6/7	4
		H1.4.2	Lead traffic misidentified by crew	Wake vortex encounter Mid-air collision with lead a/c	RG5 RA7	1
	P1.5 Crew: transmit acquisition	H1.5.1	Loss of acquisition message	Environment ensures that this is equivalent to loss of ASIA (H1.2.1)	OE1/2 OO2/3 RG5 RA6/7	4
		H1.5.2	Erroneous acquisition message	Environment ensures that this is equivalent to loss of ASIA (H1.2.1) Note : this case is not related to erroneous lead traffic (H1.4.2)	OE1/2 OO2/3 RG5 RA6/7	4
	P1.6 Crew: notify ATC of unsuccess-ful search	H1.6.1	Loss of notification of unsuccessful search	Environment ensures that this is equivalent to loss of ASIA (H1.2.1)	OE1/2 OO2/3 RG5 RA6/7	4
		H1.6.2	Erroneous notification of unsuccessful search by crew	Environment ensures that this is equivalent to loss of ASIA (H1.2.1) Note : this case is not related to erroneous lead traffic (H1.4.2)	OE1/2 OO2/3 RG5 RA6/7	4
		H1.6.3	Delayed notification of unsuccessful search by crew	Environment ensures that this is equivalent to loss of ASIA (H1.2.1) Note : this case is not related to erroneous lead traffic (H1.4.2)	OE1/2 OO2/3 RG5 RA6/7	4

Table I-3 Operational Hazard Analysis Results (continued)

Phase	Process	Hazard ID	Operational Hazard Description	Potential Operational Consequence	Environmental Considerations (from Table I-2)	Hazard Class
P1: Setup (con't)	P1.7 ATC: provide Spacing target, crew, enter spacing target	H1.7.1	Spacing target not received	Environment ensures that this is equivalent to loss of ASIA (H1.2.1)	OE1/2 OO2/3 RG5 RA6/7	4
		H1.7.2	Spacing target miscommunication	Wake vortex encounter Mid-air collision with lead a/c	OE1/2 OO2/OO4 RG5 RA6/7	1
		H1.7.3	Crew fails to enter spacing target	ASIA fails to engage; Environment ensures that this is equivalent to loss of ASIA (H1.2.1)	OE1/2 OO2/3 RG5 RA6/7	4
		H1.7.4	Crew enters incorrect spacing target	Wake vortex encounter Mid-air collision with lead a/c	OE1/2 OO2/OO4 RG5 RA6/7	1
P2: Clearance for procedure	P2.1 Controller issues clearance	H2.1.1	Loss of clearance for ASIA	Environment ensures that this is equivalent to loss of ASIA (H1.2.1)	OE1/2 OO2/3 RG5 RA6/7	4
	P2.2 Flight crew accepts clearance	H2.1.2	Erroneous clearance for ASIA	Environment ensures that this is equivalent to loss of ASIA (H1.2.1) Note : this case is not related to an erroneous ASIA clearance (H1.4.2)	OE1/2 OO2/3 RG5 RA6/7	4
		H2.2.1	Loss of flight crew acknowledgement of clearance for ASIA	Environment ensures that this is equivalent to loss of ASIA (H1.2.1)	OE1/2 OO2/3 RG5 RA6/7	4
		H2.2.2	Erroneous acknowledgment of ASIA clearance by flight crew	Environment ensures that this is equivalent to loss of ASIA (H1.2.1) Note : this case is not related to an erroneous ASIA clearance (H1.4.2)	OE1/2 OO2/3 RG5 RA6/7	4
P3: Conduct Procedure	P3.1 Crew: adjust speed based on system commands	H3.1.1	Erroneous speed maintained by flight crew	Wake vortex encounter Mid-air collision with lead a/c	OE1/2, O2/OO4, RG5, RA6/7	1
		H3.1.2	Loss of guidance during ASIA procedure	Environment ensures that this is equivalent to loss of ASIA (H1.2.1)	OE1/2 OO2/3/4 RG5 RA1/6/7	4
		H3.1.3	Erroneous guidance during ASIA procedure	Wake vortex encounter Mid-air collision with lead a/c	OE1/2, OO2/4, RG5, RA6/7	1

Table I-3 Operational Hazard Analysis Results (continued)

Phase	Process	Hazard ID	Operational Hazard Description	Potential Operational Consequence	Environmental Considerations (from Table I-2)	Hazard Class
P3: Conduct Procedure (con't)	P3.2 ATC: monitor separation	N/A		Identical to current operational procedure	N/A	N/A
	P3.3 ATC: instruct breakout	N/A		Identical to current operational procedure	N/A	N/A
	P3.4 Crew: perform breakout	N/A		Identical to current operational procedure	N/A	N/A
P4: Complete approach spacing procedure	P4.1 ATC: issue clearance for landing	N/A		Identical to current operational procedure	N/A	N/A
	P4.2 Crew: fly final approach speed and land	N/A		Identical to current operational procedure	N/A	N/A
	P4.3 Crew: execute missed approach	H4.3.1	Unnecessary missed approach due to ASIA	Environment ensures that this is equivalent to loss of ASIA (H1.2.1). The major impact is on performance since unnecessary missed approach is conducted.	OE1/2, OO2/4/5 RG5, RA6/7	4 Note
		H4.3.2	Missed approach necessary but not started	Wake vortex encounter Mid-air collision with lead a/c	OE1/2 OO2/4/5	1

Note: *Although hazard 4.3.1 leads to minor impact from a safety perspective, go around procedures adversely impact the efficiency of operations. Therefore, "nuisance" go around resulting from failures associated with hazard 4.3.1 should be limited since the impact is that the ASIA function does "not perform its intended function."*

The following four sections explain the rationale for the entries in Table I-3.

I.2.2.1.1 Setup: Phase 1 Hazards of ASIA

The process of providing vectors (P1.1) is considered to be identical to current procedures and there is no new reliance on the ASA equipment to complete this part of Phase 1 of ASIA. Therefore no new hazards are identified for this part of the procedure, and this part of the operation is assumed to be safe.

Process 1.2 is a new process that is associated with ASIA. The hazards of non-completion or incorrect completion of the flight crew entry of final approach speed, identified in hazard 1.2.1, are analyzed. The process would not be completed if the flight crew were to not complete entry of the final approach speed. In this case the CDTI user interface and ASSAP must be coordinated to detect that no entry has been made, and to disable any further processing (RA6). Because of the radar controlled environment (OE1), the single stream approach operation (OE2) and the mixed equipage design (OO3), the procedure must be aborted and reversion to standard procedures (RA7/RG5) takes place. This will not create unsafe conditions since minimum spacing must be achieved prior to the lead aircraft crossing the threshold (OO2).

In the case where process 1.2 is completed based on erroneous information (hazard 1.2.2), it is assumed that the most likely reason is due to an incorrect flight crew entry of the planned final approach speed (RA4/7), although this is also possible due to an airborne system internal failure (RA1/2). An incorrect entry could possibly result in wake vortex separation standards being violated, or even eventually lead to a mid-air collision if corrective actions are not taken. Based on the analysis to be presented below, however, a mid-air collision can be avoided with high probability by using appropriate error checking in ASSAP and/or the CDTI. A wake vortex separation violation is mitigated by use of an ASIA separation monitoring function.

Hazards 1.3.1 and 1.3.2 are associated with the callout for traffic to follow (TTF) from ATC. Hazard 1.3.1 results from a miscommunication or misunderstanding of the correct traffic to follow (RG5, RA7). In this case the flight crew selects the wrong traffic. Specific outcomes of such a mistake are very scenario dependent but in the worst case either wake vortex separation minima or a mid-air collision could result. The fault-tree analysis assesses the risk of such an outcome.

Hazard 1.3.2 results if the intended target is never communicated. In this case the procedure must be aborted. Similar to the system response to hazard 1.2.1, in this case the CDTI and ASSAP must work together, with perhaps a time-out mechanism, to disable the provision of guidance when there is no target identified. With the same assumptions on the environment (OE1/2, OO2/3, RG5, RA6/7), this hazard can lead to the same consequences as hazard 1.2.1.

Hazards 1.4.1 and 1.4.2 are associated with the process of identifying the target on the CDTI. Hazard 1.4.1 occurs if the lead traffic is not found; in this case, the procedure must be aborted. This hazard can be related to the flight crew failing to identify the target (RA7) or the airborne system failing to display the aircraft (RA1/6). The impact can be limited to reverting to standard procedures with the same assumptions on the environment (OE1/2, OO2/3, RG5, RA6/7) as for hazard H1.2.1. Hazard 1.4.2 results when the lead traffic is misidentified (RG5, RA7), in which case the potential consequences are the same as with hazard 1.3.1, namely, possible wake vortex separation minima violation or mid-air collision. ASA equipment may play a direct role, however, in producing hazard 1.4.2; therefore, these hazards are included in further analysis of the potential operational consequences.

Hazards 1.5.1 and 1.5.2 result when the flight crew communication back to ATC that the target has been successfully acquired does not get through or is corrupted. In this case, both hazards result in the same outcome as hazard H1.2.1 with the same environment assumptions (OE1/2, OO2/3, RG5, RA6/7): the procedure is aborted. The incorrectly communicated acquisition message has the same result as a no communication; if ATC does not get a clear indication that the target has been identified, no clearance to proceed can be issued to the flight crew.

Hazards 1.6.1, 1.6.2, and 1.6.3 result when an unsuccessful search is not communicated or is communicated incorrectly. In the case where the communication is not received, the clearance to proceed can not be issued and reversion to standard procedures is necessary. Likewise, for a misunderstood communication, if ATC does not get a clear message that a successful target search has been completed, the assumption must be that the search was unsuccessful and the ASIA procedure is to be abandoned. These hazards result in the same outcome as hazard H1.2.1 with the same environment assumptions (OE1/2, OO2/3, RG5, RA6/7): the ASIA procedure is aborted and aircraft is instructed to revert to the standard approach procedure.

Hazard 1.6.3 results when the search is taking too long. As depicted in Figure I-6, the net result is reversion to standard procedures.

Hazards 1.7.1, 1.7.2, 1.7.3, and 1.7.4 result when a failure of the spacing target communication occurs. As identified in the table, this can occur in one of four ways; first, if the spacing target is not received (H1.7.1) or the flight crew does not enter the target (H1.7.3), the procedure must be abandoned. These hazards result in the same outcome as hazard H1.2.1 with the same environment assumptions (OE1/2, OO2/3, RG5, RA6/7): the ASIA procedure is aborted and aircraft is instructed to revert to standard approach procedure. Likewise, the ATC to flight crew communication could be corrupted (H1.7.2), resulting in an incorrect target being entered. Alternatively, the information could be communicated correctly but then entered incorrectly by the flight crew (H1.7.4). In either hazard 1.7.2 or 1.7.4, the result can be a wake vortex separation minima violation or a mid-air collision.

I.2.2.1.2 Clearance for Approach Spacing: Phase 2 Hazards of ASIA

Phase 2 of the procedure consists of two steps – the issuing and the acceptance of the clearance for the flight crew to proceed to follow the automated guidance from the ASA systems. The possible hazards that are identified with these processes are that (H2.1.1) the clearance from ATC is lost, (H2.1.2) the clearance from ATC is misunderstood, (H2.2.1) the acknowledgement from the flight crew is not received, and (H2.2.2) the acknowledgement from the flight crew is misunderstood. If the clearance or acknowledgement is misunderstood it is effectively equivalent to non-receipt. In any of these cases once again reversion to standard procedures is required. These hazards may result in a small increase in workload for both the controllers and flight crews but the increase is assumed to be of minor criticality, and therefore these hazards are not further examined in this study.

I.2.2.1.3 Conduct Approach Spacing: Phase 3 Hazards of ASIA

Phase 3 of the ASIA procedure depends to a large extent on the ASA equipment. This is the most critical phase from the perspective of ASA requirements and it is examined in significant detail in the later sections. The primary process that is of interest to this analysis is the use of the equipment by the flight crew for speed guidance during the approach (P3.1).

Hazard 3.1.1 takes place if the flight crew does not follow the speed guidance; in this case a wake-vortex separation minima violation or a mid-air collision is possible.

Hazard 3.1.2 results if the guidance is lost during the procedure. This can occur due to detected ASA equipment failures, and is avoided by requiring minimum equipment continuity (RA1, RA6). If automated airborne guidance is lost, ATC is expected to provide guidance through the rest of the approach, as is done without ASIA.

Hazard 3.1.3 results when the ASIA system provides incorrect guidance to the flight crew. This hazard can result in wake vortex encounter or eventually a mid-air collision. The fault-trees resulting from this hazard are examined in detail in later sections along with additional supporting analysis.

Hazards related to processes P3.2 where ATC monitors aircraft approaches and P3.3 where ATC issues a breakout instruction are unchanged from current operations. Therefore no new hazards are identified for this part of the procedure, and this part of the operation is assumed to be safe.

Hazards 3.4.1 and 3.4.2 are a lack of or improper execution by the flight crew of a breakout when instructed or commanded by ATC. As there is no difference from existing procedures, there is no safety degradation in executing a missed approach with ASIA. Therefore no new hazards are identified for this part of the procedure.

I.2.2.1.4 Completion of Approach Spacing: Phase 4 Hazards of ASIA

Phase 4 of the procedure requires the flight crew to fly a normal approach and landing. Although no active guidance is provided by ASIA during this operational phase, ASIA continues to monitor spacing. If the minimum spacing is broken an alert is generated an alert is generated. If the crew determines that it can not recover from the spacing error, a missed approach may be executed.

The only hazards that occur during this phase that are different from current procedures are when the crew performs a missed approach based on incorrect information from ASIA’s alerting. Hazard 4.3.1, therefore, is an unnecessary missed approach due to ASIA. This hazard is not considered as a safety issue; therefore, it is not analyzed in the fault trees.

Hazard 4.3.2, is a missing alert when one is necessary. This hazard can result in wake vortex encounter or eventually a mid-air collision. The fault-trees resulting from this hazard are examined in detail in later sections along with additional supporting analysis.

I.2.2.2 Failure-Mode Analysis

The failure mode matrix shown as Table I-4 is intended to provide a check list to be sure that all potential failures are covered in the hazard and fault tree analysis. Failures are listed for both systems and information elements. The fault tree analysis that follows incorporates each of the errors or failures listed in the table that are specific to the actual application. At least one relevant fault-tree figure is provided in the third column for reference purposes.

Table I-4 Failure Mode Matrix

Required Information Element or System	Failure or Error	Relevant Figure(s) from Fault-tree analysis
ADS-B	System failure resulting in persistent error	Figure I-8
TIS-B	System failure resulting in persistent error	Figure I-8
ASSAP	System failure resulting in erroneous information	Figure I-8
CDTI	System failure resulting in erroneous information	Figure I-8
Navigation (lead)	Integrity failure	Figure I-9
Navigation (trail)	Integrity failure	Figure I-8
State Vector	Misleading information	Figure I-8
Planned final approach speed	Wrong approach speed	Figure I-11
Planned separation	Incorrect communication or entry	Figure I-11
ID entry	Incorrect entry	Figure I-10
Ground surveillance and automation	System failure	Figure I-15, Figure I-16

I.2.2.3 Fault Tree Analysis

The two potential operational consequences that are of significant criticality that are identified above in the hazard analysis are:

1. Wake vortex encounter

2. Mid-air collision.

ICAO procedures for ILS approaches are specifically designed on the basis of numerical risk based on the Collision risk model (ICAO doc 9274). As one of the potential risks on such an ILS approach, a wake-vortex encounter, i.e., an encounter that can cause a serious aircraft upset, is considered to be a severe-major failure requiring a probability less than the order of 10^{-7} per operation. A mid-air collision is considered catastrophic; and the probability is required to be less than the order of 10^{-9} per operation.[14]

It is the purpose of this section to present a fault tree analysis of these two operational consequences in order to derive some ASA system requirements. The fault-tree analysis includes consideration of the earlier hazard analysis of §I.2.2.1. The relevant hazards as described in §I.2.2.1 are accounted for in this analysis. Table I-5 below repeats the hazards from Table I-3 that have relevance to either of these two operational consequences, and indicates the figure in the fault tree analysis below in which these hazards are treated. It is important to recognize that an operational hazard may appear at any level within the fault tree, depending on the events that contribute to that hazard, i.e., the hazard may be a leaf event itself, or an intermediate gate in the fault tree that is contributed to by more basic events.

Table I-5 Operational Hazard Mapping to Fault Trees

Phase	Process	Hazard ID	Operational Hazard Description	Relevant Figure from Fault Tree Analysis
P1: Setup	P1.1 (ATC provides vectors)	H1.2.2	Erroneous approach speed entered	Figure I-11 Figure I-12 (Note)
	P1.3 ATC: provide callout for traffic to follow	H1.3.1	Erroneous traffic call out	Figure I-10
	P1.4 Crew: Identify target on CDTI	H1.4.2	Lead traffic misidentified by crew	Figure I-10
	P1.7 ATC: provide Spacing target, crew, enter spacing target	H1.7.2	Spacing target miscommunication	Figure I-11
		H1.7.4	Crew enters incorrect spacing target	Figure I-11
P3: Conduct Procedure	P3.1 Crew: adjust speed based on system commands	H3.1.1	Erroneous speed maintained by flight crew	Figure I-8
		H3.1.3	Erroneous guidance during ASIA procedure	Figure I-8
P4: Complete approach spacing procedure	P4.1 ATC: issue clearance for landing	H4.3.2	Missed approach necessary but not started	Figure I-7

Note: *Hazard 1.2.2 can occur on either the lead ship or the trail ship; this is identified in the fault-trees that follow below.*

As discussed in §I.2.2.1, several of the hazards identified in the hazard analysis do not lead to high criticality operational consequences and are considered to be more of a

[14] This analysis was completed based on the assumption that the approach spacing application will last approximately 15 minutes. This is based on an assumption of a 30 nmi final approach segment flown at a speed of 125 knots.

concern from an operational viability perspective, e.g., hazards 1.4.1, 1.6.3, and 4.3.1. Hazard 4.3.1 is considered as a failure of the system in its intended function and is treated in a later section.

I.2.2.3.1 Fault Tree Analysis of Wake Vortex Encounter

The fault-tree analysis begins with an examination of the likelihood of a wake vortex encounter during an approach. Figure I-7 presents the high-level fault tree for this occurrence. The purpose of the figure and the associated analysis and requirements described below is to substantiate one possible solution (ASOR) to achieve the required 10-7 per hour maximum (order of magnitude) failure rate. The second level of Figure I-7 represents a selected allocation of requirements. The values for “OP/SYS ERRORS” and “W/V SEPARATION ALERT” are determined bottom-up by subsequent analysis in Figure I-8 and Figure I-13.

This analysis provides one possible solution for the allocation of requirements in order to comply with the limit for the required maximum failure rate. This analysis provides one mean of achieving the high-level safety requirement by selecting one combination of system requirements. However, it is recognized that other combinations of system requirements could be selected in order to achieve the same goal.

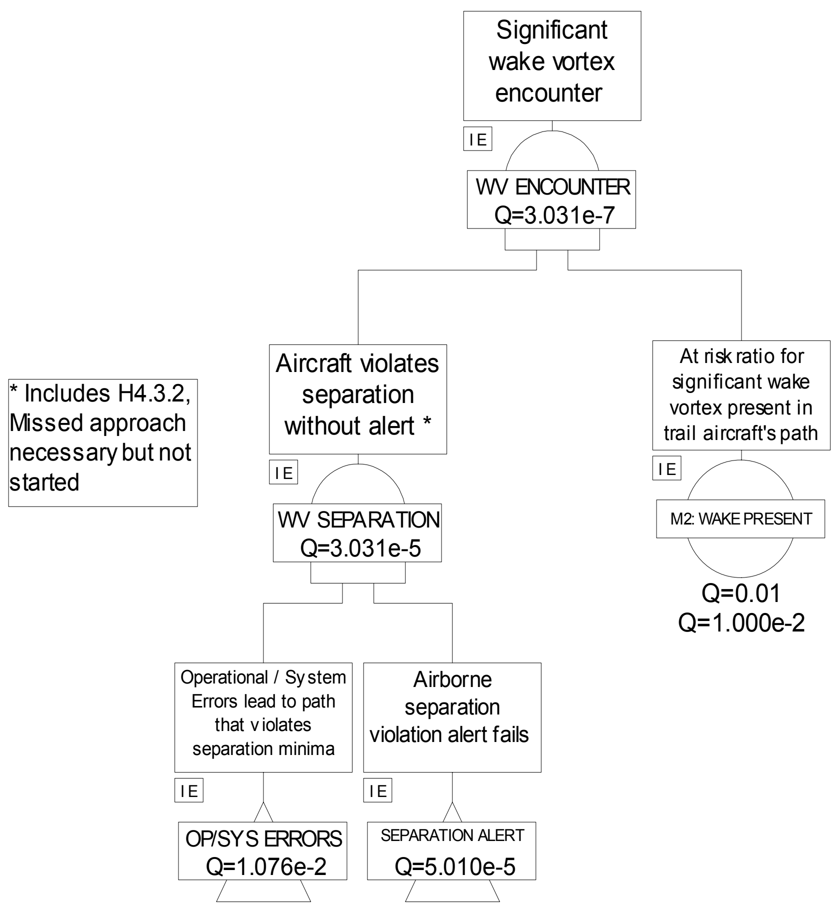

Figure I-7 High Level Fault Tree for Wake Vortex Encounter Analysis

The wake vortex encounter can occur only when the trail aircraft violates the separation minima and there is a wake present to upset the aircraft (depicted by the top AND gate in the fault-tree). Since the ASIA system is designed to avoid wake vortex separation violations, a significant separation violation only occurs if there are unexpected system or operational errors and an airborne violation alert (RA6) fails.

This analysis assumes no mitigation due to air-traffic control. The reason for this is that the analysis assumes that wake vortex encounter could take place shortly after a separation violation; it is assumed that ATC has no responsibility to notice the violation. Therefore, the responsibility for avoiding a wake vortex separation violation is assumed to be on the airborne side, i.e., via airborne alerts generated by ASIA.

Another important assumption is the probability of a wake being in the trail aircraft's path (the "at risk ratio"). Our assumption is that the wake vortex separation that the flight crews have to maintain is numerically equal to the separation that air-traffic control currently has to maintain on approach. When inside these minima, which occurs typically today during visual approaches, a possibility of a wake vortex encounter is assumed. The probability of the encounter, however, is somewhat uncertain. Due to the uncertainty of this event, a very conservative number of 10^{-2} was adopted. This assumption was not validated analytically but was derived based on interviews with line pilots, experienced in flying visual approaches well below the current IMC wake vortex separation standards. The consensus of the flight crews who discussed this was that 10^{-2} is an extremely conservative assumption**. It is noted, however, that this is one key assumption of the analysis that will need further validation before certification / operational approvals for ASIA can take place.**

The assumption on the risk ratio results in a requirement that operational and system errors be held to 10^{-5} or lower. If this assumption turns out to be invalid, a higher level of certification may be required for systems supporting this application. This value is achievable through a combination of system requirements on guidance, error checking, and alerting. It is necessary to have an alert for separation violations, as shown in the figure, as a mitigation to other potential system failures. The failure sub-trees for the operational/system errors and the alert are further analyzed below. The analysis now proceeds to work down through more detailed levels of the fault tree, working from left to right through the sub-trees of Figure I-7.

Note that the overall probability of the AND gate labeled "WV Separation" does not equal the multiplicative probability of the two gates below it; this is because the two gates feeding this AND gate are not independent (they contain "common mode" failures).

I.2.2.3.1.1 Operational and System Errors Leading to Wake Vortex Encounter Path

Figure I-8 shows the fault-tree for the left-most branch of Figure I-7. This branch considers operational and system errors that could potentially lead to a flight path that violates wake vortex separation minima.

Two operational hazards are identified at the second level of this fault-tree. First, there is a possibility that the flight crew (Hazard H1.4.2) has misidentified the traffic; second, the system may provide misleading guidance to the flight crew (Hazard H3.1.3).

I.2.2.3.1.1.1 Misidentification of Lead Traffic

Consider the possibilities that may lead to traffic misidentification. First, a significant, persistent error in the state vectors for the lead traffic might result in another target being selected. Second, the trail ships' navigation system may have errors that result in a similar effect. Third, an incorrect target ID might have been conveyed to the flight crew or the flight crew may inadvertently select the wrong target (identified as Hazards H1.3.1 and H1.4.2). Finally, the CDTI or ASSAP sub-systems may malfunction in a way that causes the misidentification.

Working down to the fourth level on the left-hand side of Figure I-8, a persistent state vector error may be caused by a persistent error in the ADS-B system, or an undetected lead ship navigation integrity failure.

A persistent error in ADS-B or TIS-B reports is presumed to have a probability on the order of 1 in 10^{-5} per flight hour. Proposed ADS-B messaging and cyclic redundancy coding (CRC) coding schemes provide a single message error rate of no more than this order, and generally a much lower order. The 10^{-5} value assumes a combination ADS-B hardware and software errors, and error correction coding.

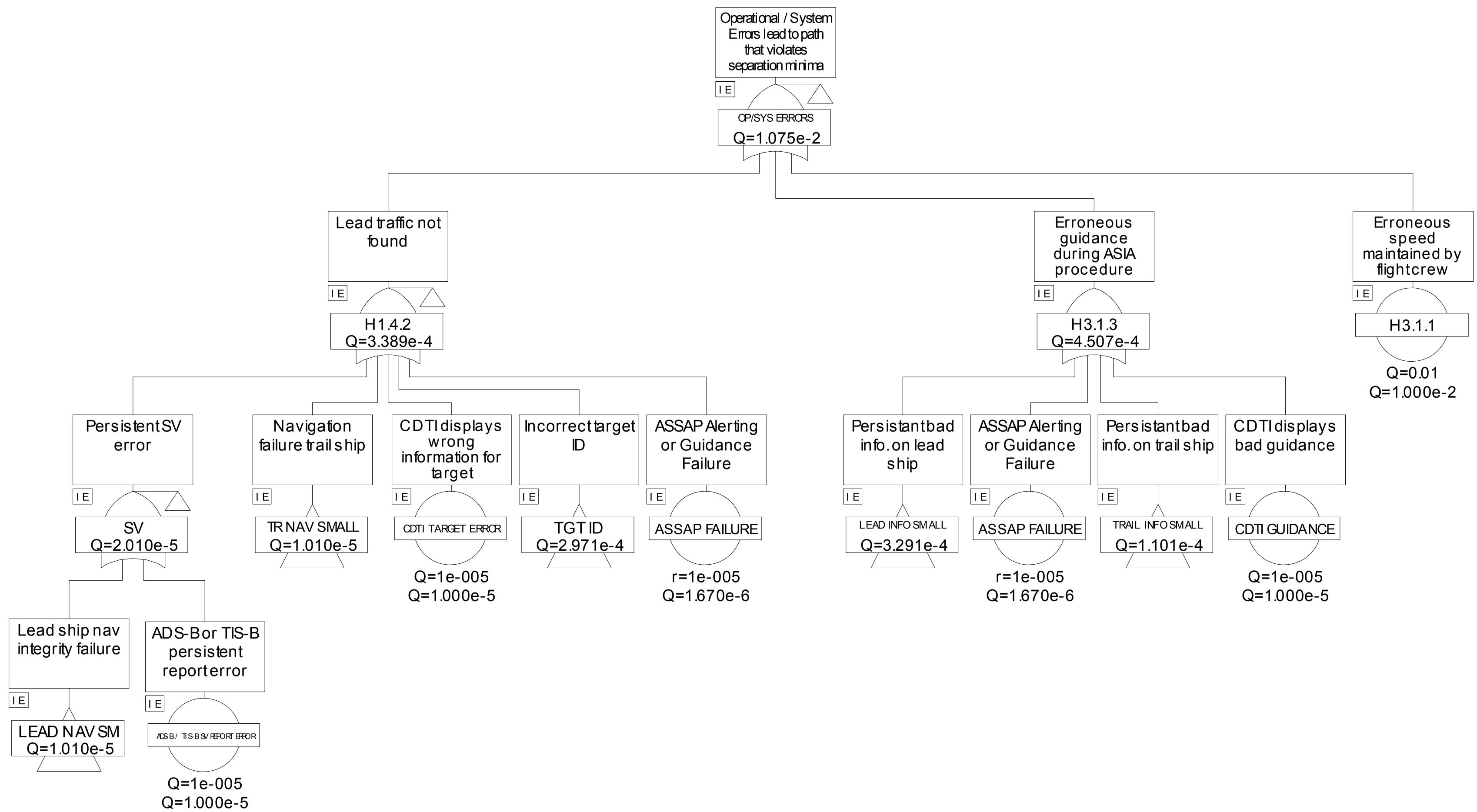

Figure I-8 **Operational / System Errors Lead to Path That Violates WV Separation Minima**

Figure I-9 illustrates the sub-tree for a lead-ship navigation integrity failure. In this tree there are two bottom level events: an integrity failure of the lead ship and an area-wide navigation integrity failure. The single ship failure represents an integrity failure of the lead ships' on board navigation system. This failure is assumed to take place with a per operation rate of 10^{-5}. An area navigation failure is a common mode failure with the trail ship, and the same failure will be included in the trail ship's fault tree. An area navigation failure affecting both the lead and trail ship is assumed to occur with a frequency that is two orders of magnitude lower than a single ship failure, i.e., with a per operation rate of 10^{-7}. This is consistent with signal in space integrity requirements for GPS WAAS and LAAS (see ICAO Annex 10, Table A2-4). The total of the lead ship's navigation system integrity failure results in a per operation rate of 1.01×10^{-5}.

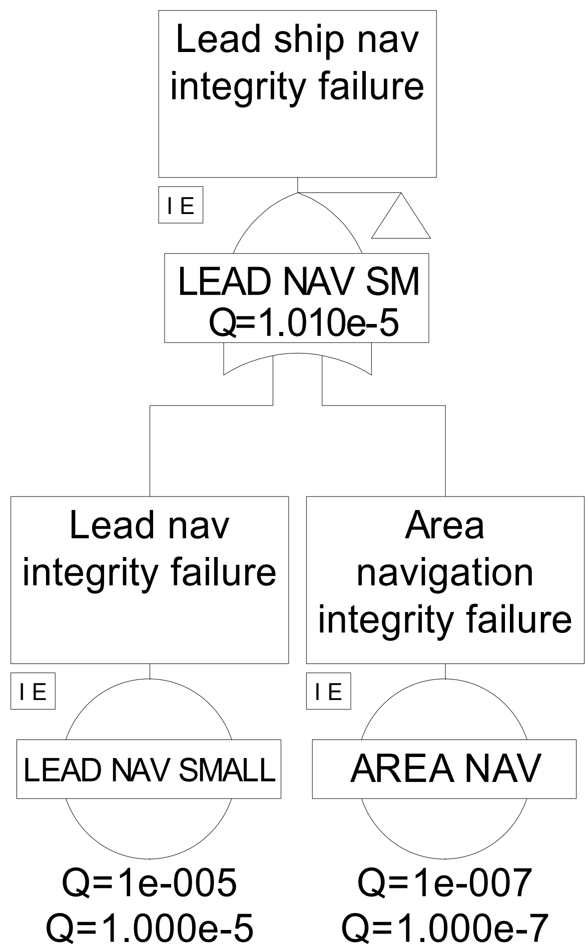

Figure I-9 Fault Tree for Navigation Integrity Failure of Lead Ship

Figure I-10 illustrates the fault tree for an incorrect target ID. It is assumed that a crosscheck is performed by the flight crew when the target ID is entered. Therefore, an incorrect target ID is propagated when there is an incorrect initial entry and the crosscheck fails. An incorrect entry takes place when incorrect data is entered into the system, through mistaken entry of the flight ID, selection of the wrong target, or through miscommunication. Miscommunication takes place on the controller side, on the flight crew side, or due to the communications system corrupting the data. Our assumptions are that communications system failures resulting in a miscommunication are on the order of 10^{-5} per flight hour, and that a human error is on the order of 10^{-2} per communication, as per the (introductory material reference).

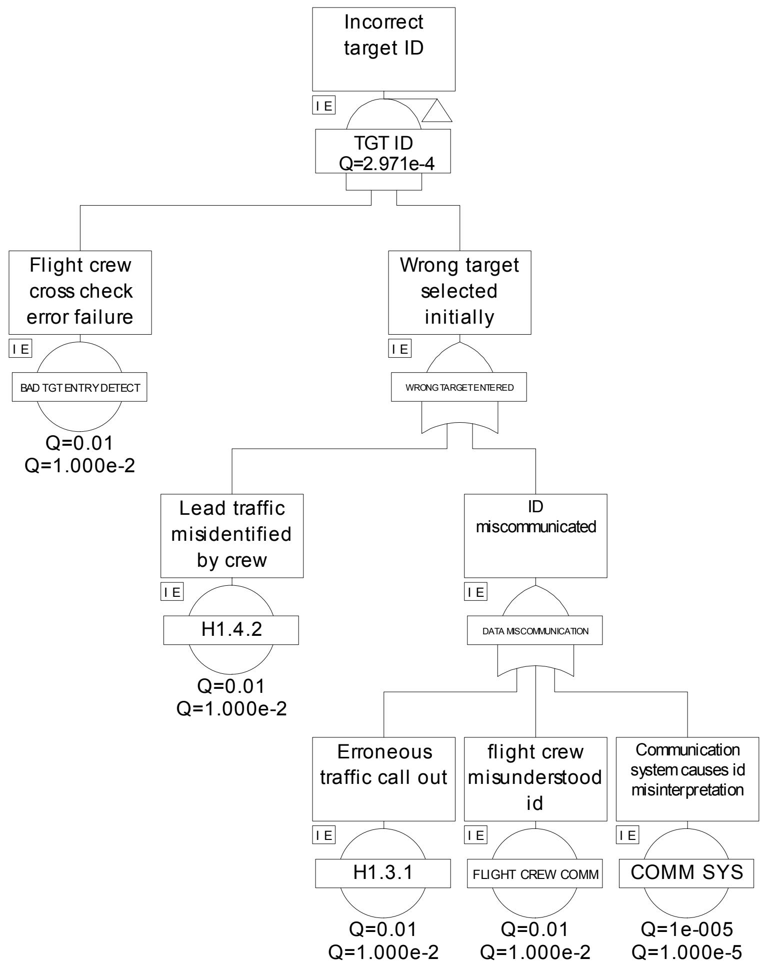

Figure I-10 Incorrect Target ID

I.2.2.3.1.1.2 Misleading Guidance

The right hand side of the tree in Figure I-8 shows four basic failures that would result in misleading guidance (hazard H3.1.3). These are persistent bad information on the lead ship or persistent bad information on the trail ship. In addition, a CDTI or ASSAP failure is also considered to potentially lead to this hazard.

That the bad information must be persistent is self-evident and is stated here as a requirement: temporarily corrupted data should not lead to guidance that will cause a violation of wake vortex separation minima. By temporary we mean any time epoch less than that which is required for the separation minima to be violated.

The next section examines the fault trees for persistent misinformation for the lead and trail ships.

I.2.2.3.1.1.2.1 Persistent Misinformation for the Lead Ship

Figure I-11 identifies the three major causes of persistent misinformation for the lead ship. First, an error in the lead plan data that is communicated to the trail ship will result in persistent misinformation. Second, a persistent error in the state vector information transmitted by the lead ship to the trail ship is considered. Third, if the controller provides or the flight crew enters an incorrect spacing target, or if an automated entry by ASIA is in error, and is below the wake vortex separation minima for the lead/trail weight category combination, the possibility of a wake vortex separation violation exists.

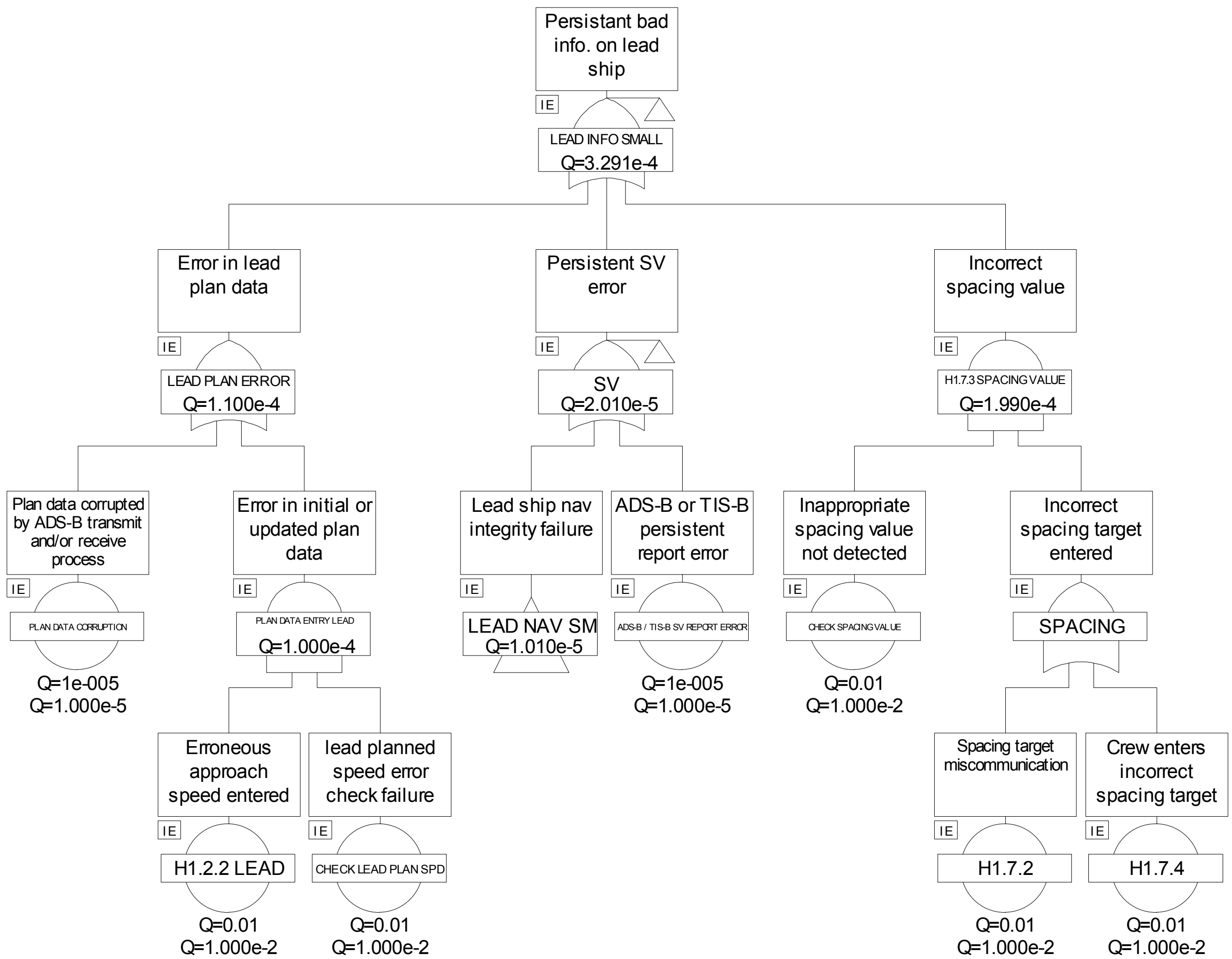

Figure I-11 Fault Tree for Persistent Bad Information for Lead Ship

I.2.2.3.1.1.2.1.1 Error in Lead Plan Data

An important potential source of incorrect information is the planned final approach speed that must be manually entered into the system during Process 1.2. The event labeled H1.2.2, representing the hazard identified with Process 1.2, is a data entry error by the flight crew of the lead aircraft. This error is assumed to occur with a failure rate of 1 per 100 approaches. Given this large failure rate due to human input, an identified requirement is that error checking be performed by the crew; in addition, it is useful to put in place automation to detect gross errors in the input. While no credit is taken in the fault tree for any automation of the error checking, error checking is listed as a requirement, because it should be possible to detect gross errors in this input, (e.g., errors that are greater than 50 or 100 knots).

It is conceivable that a small input error that is undetected by error checking could lead to a wake vortex separation minima violation. Sensitivity analysis to the failure rate of the error check found that the overall probability of a significant WV encounter is insensitive to this parameter. Much of the credit for this insensitivity lies with the required alert for a separation violation.

The combination of the input error and a failure in the input error check leads to the gate labeled "plan data entry lead." A possible error in the message transmission process that could lead to a separation violation, labeled as the event "plan data corruption," is also included with an assumed failure rate of 1 in 10^{-5} approaches.

I.2.2.3.1.1.2.1.2 Persistent SV Error

Moving to the right in Figure I-11, consider a persistent state vector error as another source of misinformation that can lead to a wake vortex separation minima violation. The sources of a state vector error were described in detail in section 4.1.1.1.

I.2.2.3.1.1.2.1.3 Incorrect Spacing Target

Finally, bad information might be connected with an inappropriate spacing target being entered by the flight crew, either due to miscommunication with ATC or due to an input error. This error should be readily detectable; hence, an error check is required on this input, although it is not considered in the fault tree.

I.2.2.3.1.1.2.2 Persistent Misinformation for the Trail Ship

The fault tree presented in Figure I-12 represents the failures that can result in persistent misinformation for the trail ship. The tree is very similar to that of the lead ship, minus the additional possible failures that result from transmission/reception problems. The trail ship also must input a final approach speed that is used in the calculation of speed guidance for the approach, therefore, a parallel input error and error check is considered for the trail ship fault tree.

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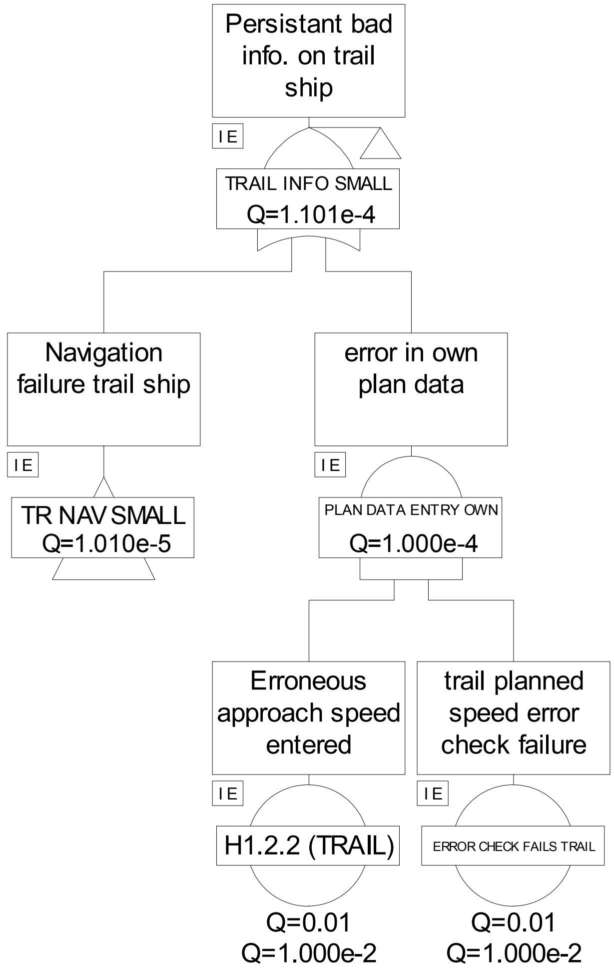

Figure I-12 Fault Tree for Persistent Bad Information for Trail Ship

I.2.2.3.1.2 Airborne Separation Violation Alert Fails

Reexamining Figure I-7, observe that an essential mitigation to a wake vortex separation minima violation is that the violation is detected by on-board systems. It is an assumption of this analysis that when such a violation is detected an alert is issued to the flight crew and that the minimum separation is promptly reestablished. We assume that this sequence of events will avoid a wake vortex encounter provided that the alert is issued before a large violation of the wake vortex minima takes place. Precise values for this minimum detection interval and the sensitivity of the detection to the navigation integrity will be discussed in a later section.

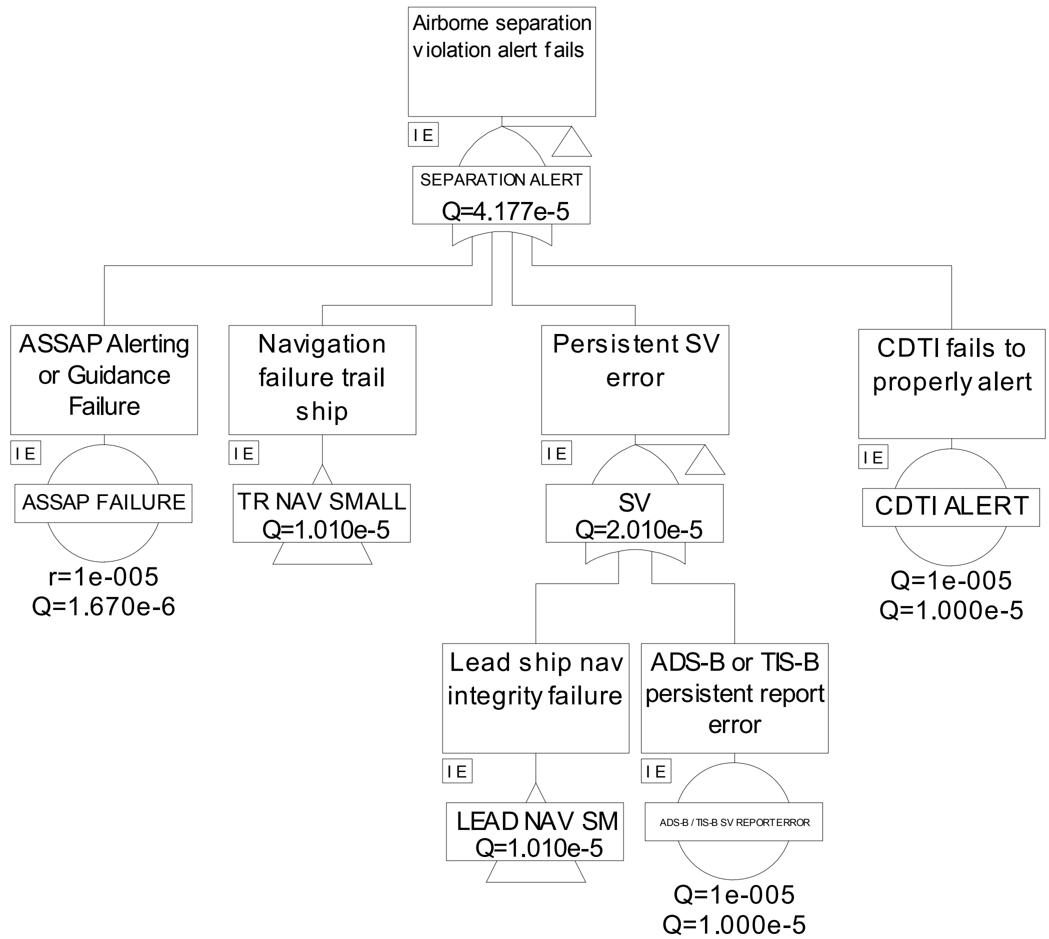

Figure I-13 Fault Tree for Airborne Separation Violation Alert Failure

The fault tree of Figure I-13 illustrates the failure mechanism for the airborne separation violation alert. The alert is based on current position estimates for both the lead and trail aircraft; the primary source of failure is state vector information from the lead aircraft and navigation information from the trail aircraft. In addition, the analysis considers a failure of the alerting algorithm itself, presumed to occur with a 10^{-5} failure rate. The state vector and navigation integrity failures are common mode failures with the operational and system errors considered in Section 4.1.1. These common mode failures are included in the calculation of the top-level event of a wake vortex encounter shown in Figure I-7.

I.2.2.3.1.2.1 Navigation Integrity Containment Requirements

While the fault tree analysis presented above provides a reasonable way to establish required failure rates for navigation integrity, it does not provide an analytic basis on which to set the required navigation containment limit. To provide some insight into the effects of various navigation containment integrity bounds, a Monte-Carlo simulation was used that employs an approach spacing algorithm that has been tested and confirmed to achieve results reasonably compatible with the operational goals of ASIA. That

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algorithm is not documented in this appendix; rather, the intent is that a final algorithm will be documented as part of the ASSAP MOPS requirements.

In any case the Monte-Carlo simulation models the aircraft approaches, approach spacing guidance, and pilot responses to the guidance inputs. The simulation also models an alerting algorithm that is triggered if the aircraft violate wake vortex separation minima.

For this particular study, the simulation was run with false information in the final approach speed plan data that is supplied to the trail aircraft. The false information is construed such that the trail aircraft is misled that the lead aircraft final approach speed will be much greater than is actually planned. This causes the trail aircraft to be issued guidance that results in frequent separation violations.

The analysis modeled a navigation integrity error as a position bias error just below the specified navigation integrity bound in the Monte-Carlo model. The direction of the error was uniformly distributed and selected at random at the beginning of each approach. Our metric in evaluating various navigation integrity containment bounds was the cumulative probability distribution of the distance inside the wake vortex separation minima at which the violation was actually detected. The integrity containment bounds were selected to correspond with the navigation integrity category (NIC) levels specified in RTCA DO-242A (ADS-B MASPS).

Figure I-14 shows the results of this analysis. The figure shows the probability of detecting the wake-vortex separation violation (the ordinate) as a function of true distance inside the wake separation minima (the abscissa). Three values of navigation integrity category were examined; the integrity category [ref DO242A] and the associated containment radius (Rc) are indicated in the figure.

As expected, detection probability degrades as a function of increasing containment radius. The 75 m containment radius performs best, with all detected violations occurring within 1000 ft of the separation minima. At Rc=185 m the detected violations are within 2000 ft of the minima, and with Rc=370 m some violations are not detected until between 2500 ft and 3000 ft of the minima. The suggested containment boundary is 75 m, as it appears to be reasonably assured that this will help to minimize the likelihood of a wake vortex encounter. The 75 m containment radius can mostly likely be met by differentially corrected GPS such as WAAS. This value represents best engineering judgement. It is feasible that a lower NIC can be used with the same safety level at the cost of some reduction in overall system performance (reduced throughput) by adding extra buffer to the spacing target.

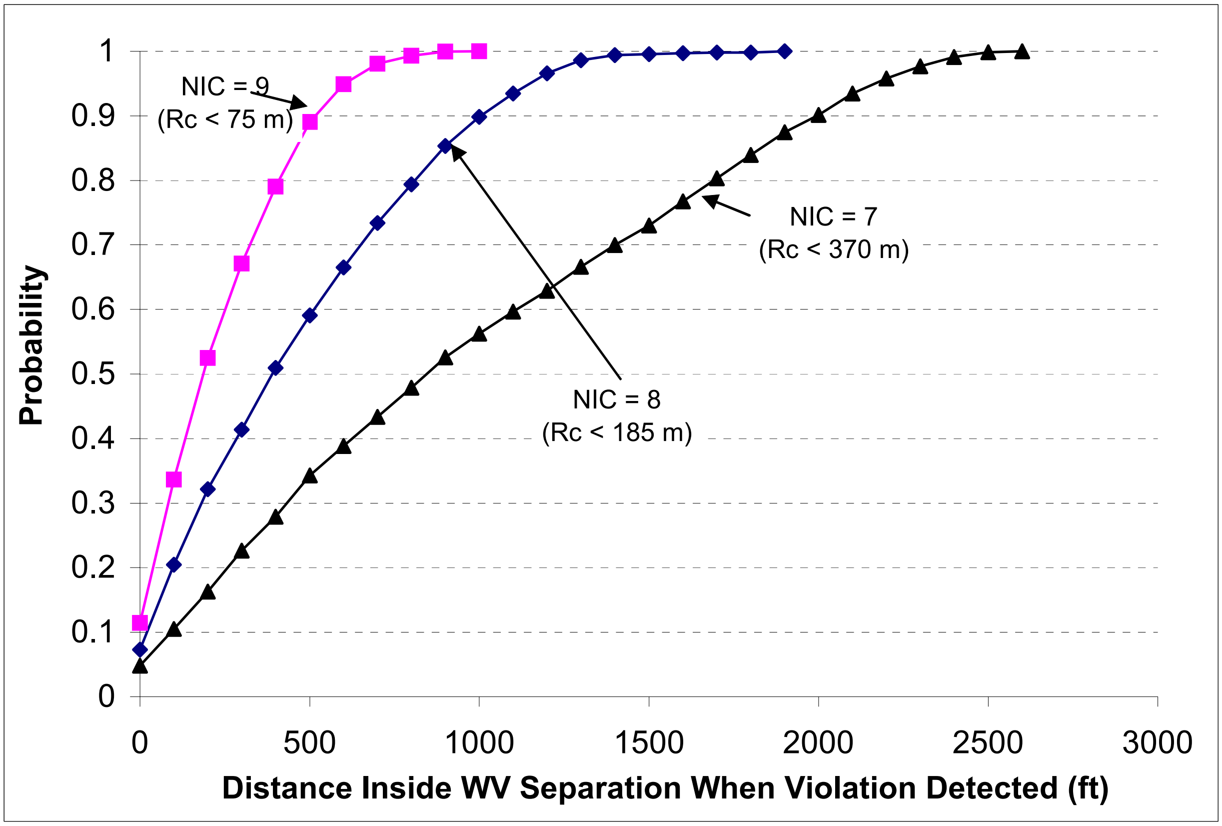


Figure I-14 Sensitivity of WV Violation Detection to Navigation Containment Bound

I.2.2.3.1.3 Summary of Wake Vortex Encounter Analysis

This section completes the analysis of the likelihood of a wake vortex encounter. We conclude that if the bottom level events occur at or below the rates described in the fault trees drawn above, the overall rate of a wake vortex encounter will be held to the 10^{-7} order of magnitude. This is an acceptable criticality (severe-major) for a wake vortex encounter.

For wake avoidance, we recommend an operating NIC of 9 (75 m containment radius) and a SIL of 2 (10^{-5} or better undetected navigation integrity failure rate).

I.2.2.3.2 Fault Tree Analysis of Mid-Air Collision with Lead Aircraft

This section analyzes the risk of a mid-air collision between the trail aircraft and the lead aircraft.[15]

We conduct a risk analysis of a mid-air collision based on two different assumptions for the information that is supplied to ATC. Although the baseline procedure as articulated earlier in this appendix assumes utilization of secondary surveillance radar (SSR), it is of

[15] The risk of a mid-air collision with another aircraft not involved in the approach is not addressed in this analysis. It is assumed that since the approach procedure is typical, that there is no introduction of additional collision risk with another aircraft beyond that of standard procedures that are considered acceptable today.

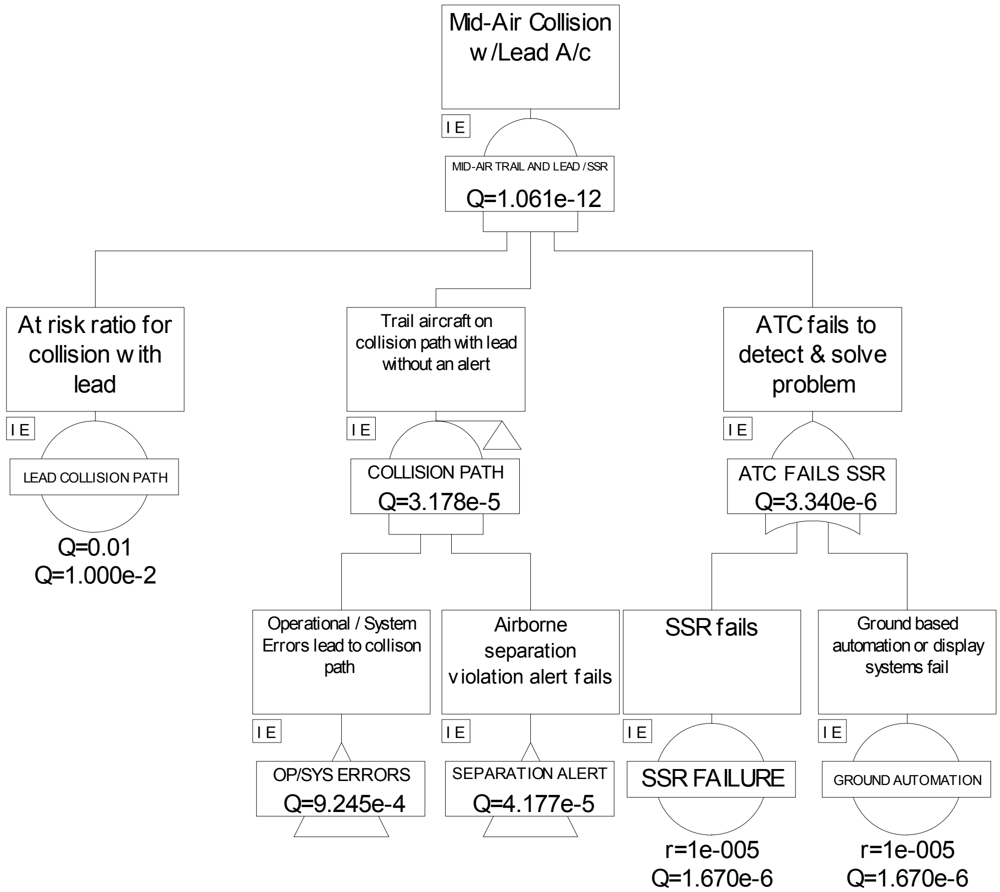
importance to also examine the case where both airborne and ATC surveillance is provided by ADS-B. The fault tree of Figure I-15 shows the assessment when air traffic control surveillance is supported by SSR. Figure I-16 contains a fault tree for the case where both air traffic control and airborne surveillance are provided by ADS-B. In the case where both ATC and airborne separation assurance are based on a common source of information, a common failure mode exists that must be accounted for in the analysis.

Figure I-15 is essentially identical to Figure I-7, with a wake-vortex separation violation being replaced with a collision path. In addition, Figure I-15 includes an additional failure of ATC to notice and correct the problem. The ATC component is introduced because it is expected that ATC will step in if a gross violation is noticed. It is not expected that ATC will be responsible for separation, other than to monitor and to help avoid a collision in the exceedingly rare situation that the aircraft are on a collision path. The hazards and failures leading to a collision path are identical to those that lead to a wake vortex separation violation; the difference is in the magnitude of the failure.

Figure I-15 assumes that ATC continues to rely on secondary radar for monitoring the situation. In contrast, Figure I-16 considers a case where ATC uses ADS-B information. Since ADS-B represents a possible eventual replacement for SSR, as a part of the probe analysis, it is useful to examine the requirements that would be necessary with such a surveillance architecture. Other than surveillance integrity, Figure I-16 assumes the same hazard and event likelihoods as Figure I-15. Table I-6 shows the resulting mid-air collision probabilities as a function of the undetected navigation failure rate. The table indicates that an order of magnitude more navigation integrity will be needed for the case where ADS-B is the sole source of surveillance information (note that the results indicated in Figure I-16 are based on a 10^{-7} integrity). Note that it is the navigation subsystem integrity, and not the other subsystem integrity levels that need to be boosted for the sole-means case.

Table I-6 Mid-Air Collision Rate vs. ATC Surveillance Source

Airborne surveillance	ATC Surveillance	Navigation Integrity Undetected Failure Rate (per flight hour)	ASIA Mid-Air Collision Rate (per operation)	Acceptable Collision Risk
ADS-B	SSR	10^{-5}	10^{-12}	Yes
ADS-B	ADS-B	10^{-5}	10^{-8}	No
ADS-B	ADS-B	10^{-7}	10^{-9}	Yes



<u>Figure I-15</u> Top Level Fault Tree for Mid-Air Collision with Lead; ATC based on Secondary Surveillance Radar

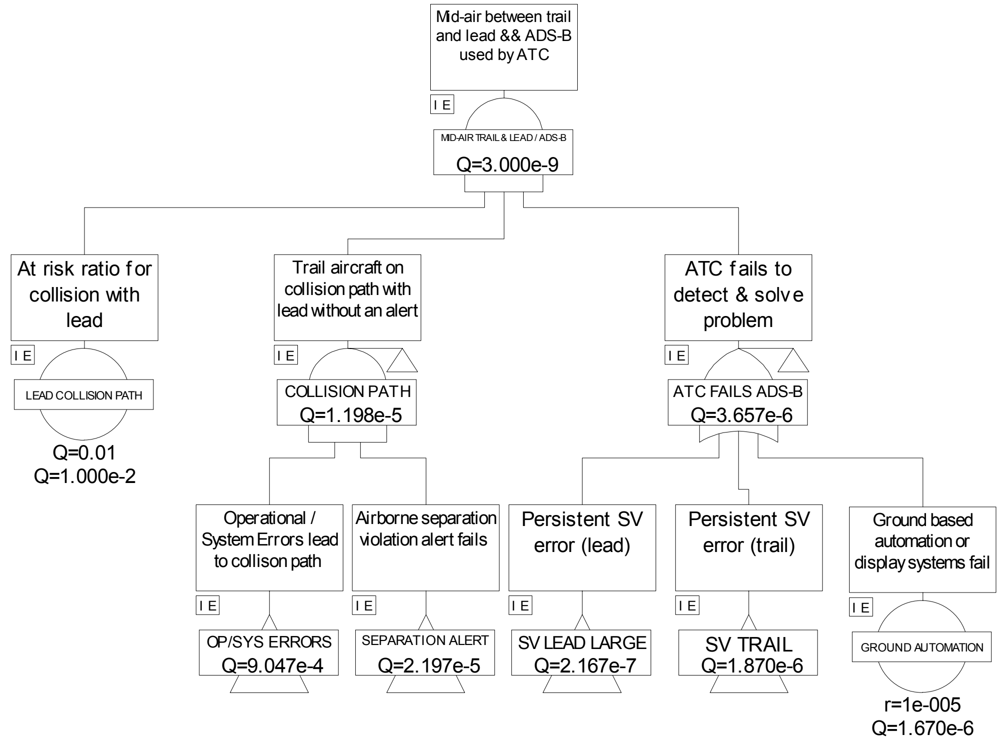


Figure I-16 Top Level Fault Tree for Mid-Air Collision with Lead; ATC based on ADS-B

As we expect that SSR will be available for a considerable time period, a 10^{-5} integrity is initially acceptable to run ASIA operations. Ultimately, if ADS-B becomes the sole surveillance source for both ATC and airborne applications, it may be necessary to have the navigation information achieve a 10^{-7} integrity. It is, however, possible that this analysis has been overly conservative in assuming the same probability for a small integrity error leading to a wake vortex minima separation violation as for a large error leading to a collision. If it can be substantiated that an integrity error of enough magnitude to cause a collision is less likely (by two orders of magnitude), then it may be possible to reduce the 10^{-7} requirement back to 10^{-5}.

I.2.3 Analysis of Requirements Supporting Intended Function of ASIA

The ASIA application is intended to increase runway throughput without increasing missed approaches. A Monte-Carlo simulation that includes a model of the surveillance environment, a model for the guidance algorithm, and a model for the flight crew response to guidance inputs was employed in order to assess requirements supporting ASIA. The simulation models wake vortex separation minima for large, heavy, and small aircraft. This analysis assumed a mix of 12% heavy, 8% small, and 80% large aircraft.

The simulation models multiple arrivals in a single stream approach. The number of aircraft arrivals is selected, and then Monte-Carlo simulations are achieved by running multiple instances of the arrival stream. Statistics are collected on the overall throughput at the runway threshold, the average separation and inter-arrival time as a function of arrival number, and the number of go-arounds. It is assumed that each time the wake vortex separation minima are broken, a go-around is issued.

Since the primary purpose of ASIA is to improve runway throughput, the simulation was set up such that deliveries to the approach stream were at an average rate of about 37 per hour, including all aircraft weight categories. The details of the simulation are presented in [ref Wang, Hammer]. The average rate of 37 per hour represents an improvement of between 4 and 5 arrivals per hour over what our simulation indicates can be with the traffic mix that is specified above.

The objective of these simulation runs was to determine surveillance requirements for update rate, position and velocity accuracy, and latency. The analysis was conducted by determining acceptable baseline values for these parameters, then degrading selected parameters to see where acceptable performance is no longer achieved. The process was methodical; the resulting requirements are sufficient and reasonable, but no claims are made that the requirements are necessary, or that they are in any way optimal.

The metric of this study is the number of actual separation minima violations that are recorded for every 1000 approaches. Generally about 25,000 approaches were run for each result. The minima violations were broken into two categories: the total violations and those that were 1,000 feet or more below the separation requirement considered "significant." Our assumption is that a "significant" violation is likely to result in a go-around whereas a technical violation of less than 1,000 feet below the minima will result in a minor but annoying disruption and increased workload for the flight crew and possibly the controllers. A limit was set of a rate of 1 per 1,000 approaches of significant violations and 2 per 1,000 approaches of total violations.

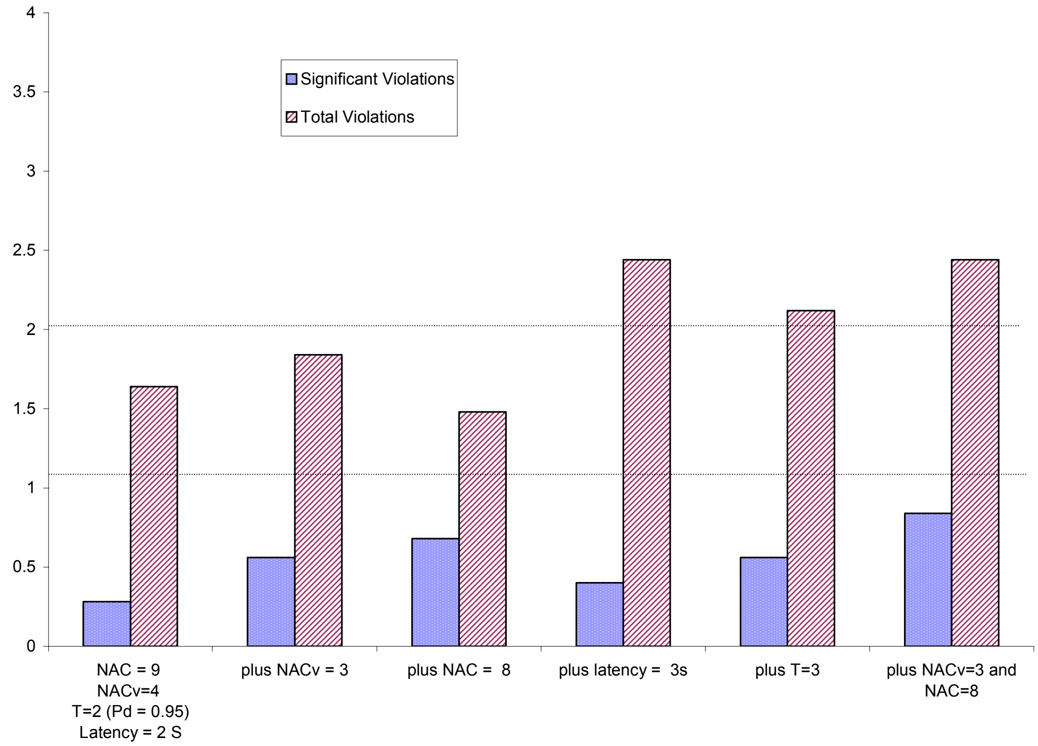


Figure I-17 Baseline of NAC=9, NACv=4, T=2 S, Latency = 2S with Variations

Figure I-17 illustrates the results of these experiments. The figure shows a baseline result on the left hand side that is augmented by various reductions in performance in the examples to the right. Figure I-17 illustrates that with NAC=9, NACv=4, a latency of 2 seconds, and an update period of 2 seconds with a 95% success rate, that the desired operational performance is achieved. Degrading either latency or update period to 3 seconds results in unacceptable performance in terms of total violations. Degrading NAC to 8 or degrading NACv to 3 still results in acceptable performance, but degrading both NAC to 8 and NACv to 3 causes the proportion of total violations to exceed the recommendation.

It is suggested, therefore, that a minimum requirement of NAC=9, NACv=4, update period of T=2 S with success probability of 0.95, and a latency of 2 seconds be the minimum requirements to initiate ASIA. Degradation of NAC to 8 or NACv to 3 during the procedure is considered acceptable to continue the operation.

I.2.3.1 System Continuity Requirements

While the safety analysis did not determine a need for a system continuity requirement for this application, the economic benefit of the application will depend on the system introducing very few missed approaches due to a continuity failure. The assumption being made is that no more than 1 in 1000 approaches should be allowed to be broken off, resulting in a continuity requirement of 99.9% per operation.

I.2.4 Requirements Summary

This section summarizes the requirements that have been derived in the sections above.

I.2.4.1 Data Requirements

Data requirements are as specified below.

Data Element ⇒ / **Performance Requirement ⇓**	**State Vector**	**Planned Final Approach Speed**	**Planned intermediate approach speeds & range from threshold**[1]	**Source of Requirement**
Navigation Accuracy Category – Position (NACp)	NACp >= 8	N/A	N/A	I.2.3
Navigation Accuracy Category – Velocity (NACv)	NACv > 4 if NAC=8 NACv >3 if NAC>=9	N/A	N/A	I.2.3
Navigation Integrity Category (NIC)	NIC=9	N/A	N/A	I.2.2.3
System Integrity Level	10^{-5} 10^{-7} (desired if ADS-B is sole-source surveillance)	Corruption probability by system < 10^{-7}	Corruption probability by system < 10^{-7}	I.2.2.3
Maximum Delay to Indicate Integrity Changes	TBD	N/A	N/A	Best Engineering Judgement
Latency of Transmitting Information	≤ 2 sec	< 15 sec	Update within 5 seconds of a change[2]	I.2.3
Maximum Age of Applicability for Dynamic Data[l]	TBD	N/A	Update Within 5 seconds of a change[2]	I.2.3
Effective Update Rate	2 Seconds	N/A	N/A	I.2.3
Report Time Accuracy	0.1 Sec	N/A	N/A	I.2.3
Continuity	>99.9% per operation			I.2.3
Availability	No Requirement			No safety dependency found
Coverage	Approach corridor			D.1
Vehicle Participation	All Vehicles on Approach			D.1

I.2.4.2 Subsystem Integrity Requirements

Based on the fault-tree analysis of I.2.2.3, the Navigation, ADS-B (combination of transmitting and receiving subsystems), ASSAP, and CDTI subsystems need to maintain an integrity of 10^{-5} per flight hour.

I.2.4.3 Processing Requirements

1. A guidance algorithm is to be specified in ASSAP MOPS.

2. Temporarily corrupted state vector data should not lead to guidance that will cause a violation of wake vortex separation minima. The probability of a persistent error due to ADS-B < 10-7.

3. A detection algorithm that alerts when wake vortex minima have been violated shall be provided.

I.2.4.4 Display Requirements

Displays shall be provisioned to allow:

1. View of flight identification, horizontal position, and altitude of surrounding traffic;

2. Selection and highlight a specific target on the display;

3. Selection of the ASIA function;

4. Input the final approach speed for own aircraft and input the other aircraft flight identification and final approach speed as well as the desired minimum target spacing;

5. Arming the ASIA tool (if the tool set requires such a function);

6. Determining that the approach algorithm is operating normally;

7. Displaying lead aircraft information to assist in monitoring the longitudinal distance with the lead aircraft (e.g., ground speed, range read-out);

8. Determining / viewing the lead aircraft position for a safe interval;

9. Viewing and utilizing the ASIA tool (e.g., speed guidance) to assist in acquiring the target position;

10. Viewing when own ship has achieved minimum target spacing, not at minimum target spacing, and at a breakout point; and

11. Determining when the spacing task is to be discontinued.

In addition:

12. Provision shall be made for the flight crew to enter planned final approach speed into the approach spacing system through the CDTI. It is expected that an FMS will act as an interface to the CDTI so that the flight crew is able to enter the necessary parameters.

13. Provision shall be made for lead traffic identification and selection on the CDTI.

14. A check shall be provided on the separation entered versus weight category wake vortex separation minimums.

15. ASIA guidance shall not be enabled if no entry is made for planned final approach speed, lead traffic identification, or desired separation.

16. An error check on the flight crew entered planned final approach speed shall detect all errors above errors greater than 100 knots.

I.2.4.5 Assumptions

Assumptions are made on systems or personnel that are beyond the scope of the requirements in this document. Satisfactory system performance depends on the following assumptions:

I.2.4.5.1 Navigation

Navigation systems are assumed to support the navigation accuracy and integrity described above.

This analysis assumed that the flight crew will be flying ILS approaches.

I.2.4.5.2 Air Traffic Control

It is assumed that controllers will have adequate tools to identify appropriately equipped aircraft (e.g., via flight strips, datablock).

It is assumed that ATC employs a conflict detection algorithm with 10-5 probability of failing to detect a violation of wake vortex separation minima.

It is assumed that the secondary surveillance radars fail with < 10-5 probability per operation.

It is assumed controllers will take appropriate action when alerted to a violation of minimum separation standards.

I.2.4.5.3 Flight Crew

It is assumed that flight crews will follow system guidance.

It is assumed that flight crews will take appropriate action when alerted to separation minima violation.

I.3 Supplemental Matter

I.3.1 Abbreviations

ASIA	Approach Spacing for Instrument Approaches
ADS-B	Automatic Dependent Surveillance-Broadcast
AOC	Airline Operations Center
ARTCC	Air Route Traffic Control Center
ATC	Air Traffic Control
ATIS	Automated Terminal Information System
CAASD	Center for Advanced Aviation System Development
CDTI	Cockpit Display of Traffic Information
CDU	Control and Display Unit
DAG	Distributed Air Ground
FAA	Federal Aviation Administration
FAF	Final Approach Fix
FMS	Flight Management System
GPS	Global Positioning System
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
MASPS	Minimum Aviation System Performance Standards
MCP	Mode Control Panel
MITRE	MITRE
NASA	National Aeronautics and Space Administration
RA	Resolution Advisory
RTCA	RTCA
TCAS	Traffic alert and Collision Avoidance System
TESIS	Test and Evaluation Surveillance and Information System
TMC	Traffic Management Coordinator
TMU	Traffic Management Unit
TRACON	Terminal RAdar CONtrol
VMC	Visual Meteorological Conditions
VOR	Very high frequency Omni-directional Radio

I.3.2 Definition of Terms

CDTI- The pilot interface portion of a surveillance system. This interface includes the traffic display and all the controls that interact with such a display. The CDTI receives position information of traffic and own-ship from the airborne surveillance and separation assurance processing (ASSAP) function. The ASSAP receives such information from the surveillance sensors and own-ship position sensors.

Flight Crew- One or more cockpit crew members required for the operation of the aircraft.

Mixed Equipage- An environment where all aircraft do not have the same set of avionics. For example, some aircraft may transmit ADS-B and others may not, which could have implications for ATC and pilots. A mixed equipage environment will exist until all aircraft operating in a system have compatable capabilities.

Desirable- The capability denoted as Desirable is not required to perform the procedure but would increase the utility of the operation.

Required- The capability denoted as Required is necessary to perform the desired application.

Traffic- One or more aircraft or vehicle(s).

Target- Traffic of particular interest to the flight crew.

Selected Target- Target that has become distinguishable from other traffic as a result of being selected.

Target Selection- Manual process of flight crew selecting a target.

I.3.3 References

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